Pleuronectiformes

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This chapter describes trends in abundance and distribution for flatfish species commonly collected in the San Francisco Estuary. For each species, abundance and distribution information is discussed in the context of life history. Brief descriptions for uncommonly collected species are contained in a concluding section.

The term flatfish refers to species belonging to several families that metamorphose from a bilaterally-symmetrical, pelagic larva to an asymmetrical, demersal juvenile. During this metamorphosis, 1 eye migrates to join the other on 1 side of the head, the body compresses and deepens, and pigment develops only on the "eyed" side.

Twelve species of flatfish from 3 families were collected from the San Francisco Estuary from 1980 through 1995: Bothidae—speckled sanddab, *Citharichthys stigmaeus*; Pacific sanddab, *Citharichthys sordidus*; California halibut, *Paralichthys californicus*; Pleuronectidae—English sole, *Pleuronectes vetulus*; starry flounder, *Platichthys stellatus;* diamond turbot, *Hypsopsetta guttulata*; sand sole, *Psettichthys melanostictus*; curlfin turbot, *Pleuronichthys decurrens*; C-O sole, *Pleuronichthys coenosus*; hybrid sole, *Inopsetta ischyra*; and hornyhead turbot, *Pleuronichthys verticalis*; Soleidae—California tonguefish, *Symphurus atricauda* (Robins and others 1991) (Table 1). All 12 species are native to the eastern Pacific Ocean.

Table 1 Total catch by species and gear type for flatfish collected between January 1980 and December 1995. See the Methods chapter, Table 1, for duration of use for different gear types.

Species	*Plankton Net Larvae*	*Plankton Net Juveniles*	*Beach Seine*	*Otter Trawl*	*Midwater Trawl*
English sole	429	94	381	19,941	426
Starry flounder	251	8	162	3,873	392
Speckled sanddab	0	46	7	17,173	82
California tonguefish	0	5	0	1,796	2
California halibut	74	0	27	590	19
Diamond turbot	268	0	23	255	9
Curlfin sole	0	0	0	123	0
Sand sole	20	0	4	70	5
Pacific sanddab	0	0	0	26	0
C-O sole	0	0	0	1	0
Hybrid sole	0	0	0	1	0
Hornyhead turbot	1	0	0	0	0

Speckled Sanddab

Introduction

The speckled sanddab, *Citharichthys stigmaeus,* is one of the most abundant shallow water flatfish, but due to its small size it is not generally caught in either recreational or commercial fisheries (Ford 1965). It does, however, contribute substantially as a food resource to flatfish that are important recreational and commercial species, such as bigmouth sole, *Hippoglossina stomata*, and California halibut, *Paralichthys californicus* (Ford 1965). The speckled sanddab ranges from Magdalena Bay, Baja California to Montague Island, Alaska (Miller and Lea 1972). It has been captured at depths from 3 to 366 m (Miller and Lea 1972), although, in southern California, it is found primarily from 1 to 60 m (Ford 1965).

Based upon ovarian egg sizes, the speckled sanddab spawns between March and October in southern California (Ford 1965, Goldberg and Pham 1987). However, maturing eggs are found in some females throughout the year, indicating that spawning is possible all year (Ford 1965). Spawning probably takes place on the open coast (Wang 1986). Multiple spawnings appear possible for mature females of all sizes (Ford 1965, Goldberg and Pham 1987).

Speckled sanddab eggs and larvae are pelagic (Ahlstrom and Moser 1975). Larvae are about 2.0 mm TL on hatching (Wang 1986). They are found throughout the year with high numbers occurring in June and July. The pelagic larval period extends for several months, and pelagic post-larval speckled sanddabs may grow larger than 40 mm (Ford 1965). Recently settled juveniles range from 26 to 54 mm TL (Ford 1965). Females reach sexual maturity at roughly 1 year and 70 to 80 mm TL (Ford 1965). They reach a maximum length of approximately 171 mm (Miller and Lea 1972), but individuals >127 mm are uncommon (Fitch and Lavenberg 1975).

Methods

Length frequency analysis (mm TL) of 1981 to 1988 otter trawl data was used to separate life stages. Fish 25 to 39 mm were considered recently settled (Ford 1965, Kramer 1990a, Kramer 1991b). The approximate size at maturity was considered to be 70 mm. For abundance and distribution analyses fish were separated into juvenile and adult age groups by a 70 mm TL cutoff length. Due to a protracted and variable pelagic period, juvenile fish (<70 mm) were grouped for analyses by year of capture rather than year of hatching.

Abundance indices and distribution analyses for both age groups were derived using the same monthly and annual grouping periods. The annual abundance index was calculated as the mean of the February to October monthly indices. To describe seasonal abundance, monthly indices were averaged for 1981 through 1988, when sampling was conducted all year. Annual distribution was the mean CPUE by region for February to October. Seasonal distribution was the mean CPUE by region and month for 1981 to 1988. Seasonal depth distribution was the mean CPUE by month for channel and shoal stations separately from 1981 to 1988. Seasonal salinity distribution was the monthly mean ±1 standard deviation of CPUE-weighted bottom salinity using 1981 to 1988 data. Seasonal temperature distributions were calculated as salinity was using CPUE-weighted bottom temperature.

Results

Catch and Length Analyses

Over 17,000 speckled sanddabs were captured in the estuary with the otter trawl, but only 82 with the midwater trawl, 46 with the plankton net, and 7 with the beach seine (see Table 1). Based upon the otter trawl catch, the speckled sanddab was the 2nd most abundant flatfish in the estuary.

Fish caught by the otter trawl ranged from 19 to 152 mm TL. Only 5 post–larval sanddabs, all <25 mm, were caught during May and June (Figure 1). Recently settled juveniles were collected all year, but relatively few were captured from July to September. Juvenile recruitment was highly variable, but occurred in 2 periods: November to January and April to June (see Figure 1). Adults were collected throughout the year. The adult age group was composed of at least 2 year classes and became more abundant during the year as juveniles grew to adult size. Few adults >125 mm were captured, and all were less than 20 mm of the maximum size of the species (that is, 171 mm, see Figure 1).

Abundance and Distribution of Juveniles and Adults

Annual Abundance

Juvenile speckled sanddab abundance increased through the study period, ranging from low of 1,544 in 1981 to a high of 38,573 in 1994 (Figure 2, Table 2). Juvenile abundance often remained stable for 2-year periods. Adult abundance ranged from a low of 1814 in 1981 to a high of 35,330 in 1993. After a large drop between 1980 and 1981, adult abundance also increased for the rest of the study period (see Figure 2, Table 3). Adults were more abundant than juveniles before 1987, but juveniles were more abundant after 1987.

Seasonal Abundance

Juvenile speckled sanddab abundance was generally lowest in late summer and early fall just before recruitment of the next year class (Figure 3, see Table 2). Juveniles began entering the estuary in late fall, reaching a minor peak during winter. After a slight decline in the spring, juvenile abundance generally peaked in late spring and early summer. Abundance declined rapidly during the summer as some juveniles grew to adult size (see Figure 1).

Adult speckled sanddab abundance increased from a spring low to a summer peak as adults returned to the estuary and as juveniles grew to adult size (see Figure 3, see Table 3). Abundance declined during the late summer and fall, leveled off in December and showed a minor mode in winter.

Annual Distribution

Juvenile speckled sanddabs were usually distributed from South Bay northward into San Pablo Bay, but during the 1987–1992 drought they were occasionally caught in Suisun Bay and the west delta (Figure 4). In years with relatively low abundance and high outflow (for example, 1982 and 1983), juvenile sanddabs did not enter San Pablo Bay. The use of South and San Pablo bays increased as overall abundance increased from 1988 to 1994. Use of South and San Pablo bays declined in 1995 with increased outflow.

Adult speckled sanddabs were distributed from South Bay northward into San Pablo Bay, except in 1983 and 1985 when they did not enter San Pablo Bay (Figure 5). Adult CPUE was always highest in Central Bay. Increased adult use of South or San Pablo bays coincided with increased juvenile use there.

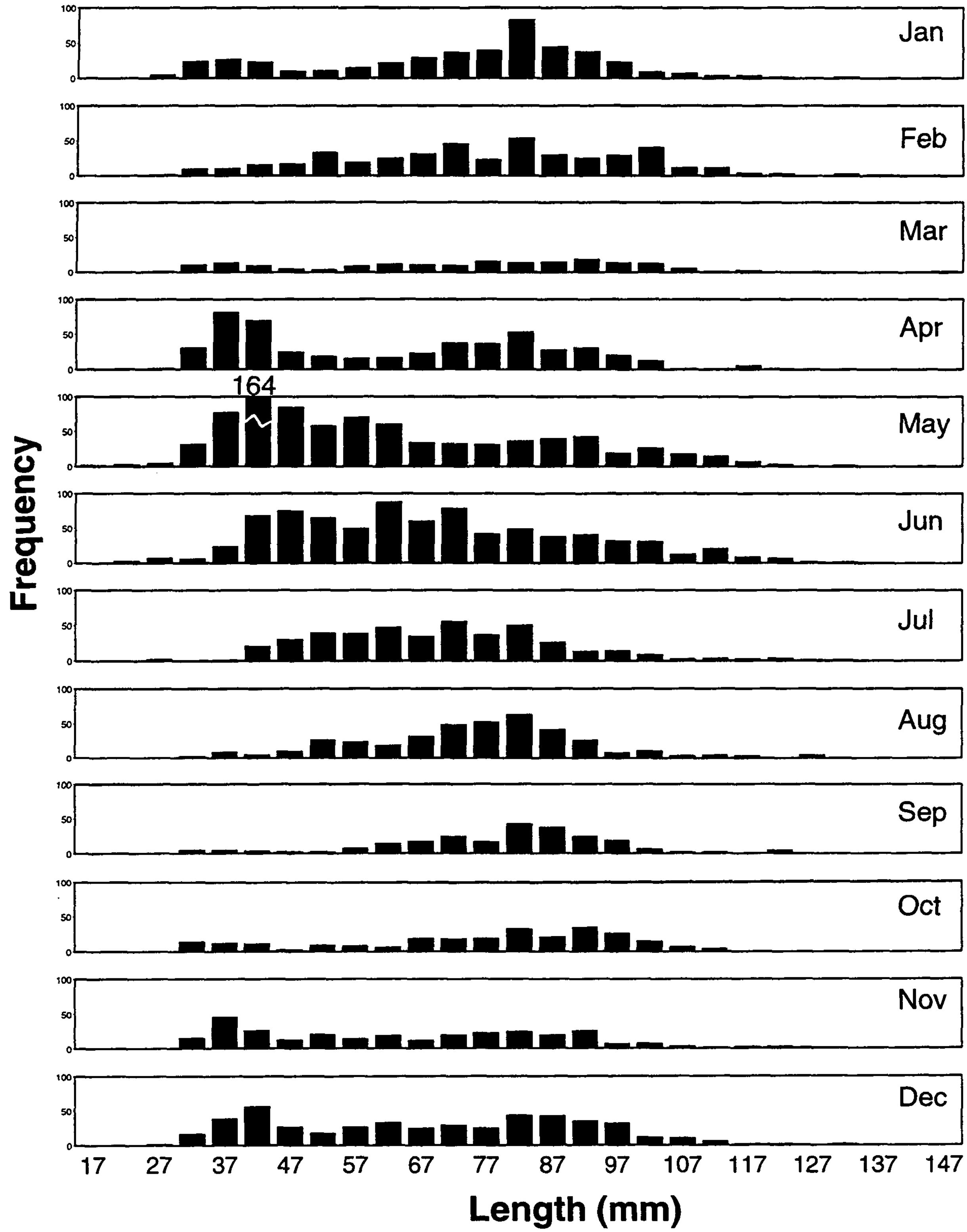

Figure 1 Length frequency (mm TL) by month of speckled sanddabs collected with the otter trawl from 1981 to 1989

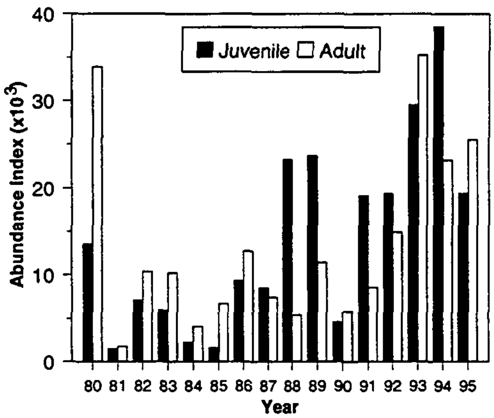

Figure 2 Annual abundance of juvenile and adult speckled sanddabs collected with the otter trawl from 1980 to 1995. Data are the means of February to October monthly indices.

Table 2 Monthly abundance of juvenile speckled sanddabs captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		44820	16309	1603	6640	20826	13273	6150	10438	2217	1286	216	13586
1981	1205	154	1016	2154	514	250	2102	6923	216	568	406	2929	1544
1982	10530	278	281	17374	21544	6330	3696	216	1250	13042	1261	436	7112
1983	854	649	534	3482	8407	16698	9097	11493	1236	2542	4993	3419	6015
1984	406	0	1605	189	6506	10934	1460	0	216	0	0	0	2323
1985	115	3732	325	1001	1277	3387	2704	838	620	892	586	4644	1642
1986	4489	5412	1563	14400	6784	40961	7898	4508	412	2140	3092	7424	9342
1987	2890	27857	7713	538	6939	8492	9031	6911	6688	3000	26407	24389	8574
1988	16797	2192	4915	37698	101672	29398	26921	4884	1728	270	1315	5031	23298
1989	5882	15402	19871	40836	13943	50470	15142	10452					23731
1990		9143	14876	1540	2785	6519	1062	2627	1512	2012			4675
1991		26456	18962	12958	34140	17539	24961	19423	10873	7012			19147
1992		25817	15832	20002	18841	15807	2970	1352	14108	59879			19401
1993		15255	9401	11996	49989	88539	60971	12991	7751	9168			29562
1994		41786	28553	28169	43352	78834	26246	45174	43753	11292			38573
1995	28953	19852	22793	4685	68672	12469	15673		9454	1758	20367	17967	19420
1981–1988	4661	5034	2244	9605	19205	14556	7864	4472	1546	2807	4758	6034	

Table 3 Monthly abundance of adult speckled sanddabs captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		81864	101011	11299	36868	46416	11109	1650	12827	2654	5280	466	33966
1981	9783	2438	830	1313	346	466	1366	8406	647	514	676	3393	1814
1982	45777	3096	1626	4610	33047	32519	404	757	7277	10316	907	728	10406
1983	3096	1582	3878	2670	3840	17437	24311	31882	1217	5598	6679	12627	10268
1984	4733	1001	1732	784	10306	6896	5145	595	4144	6598	838	1379	4133
1985	3554	23511	3608	1596	865	5190	1244	10952	6222	7518	8086	12180	6745
1986	14401	11896	6320	29366	6622	24557	17573	12012	4078	2918	1405	4737	12816
1987	4292	17222	5181	0	3459	2216	11466	8840	12683	6382	12124	13327	7494
1988	8112	2945	2040	19157	9707	7722	5106	487	1340	568	704	1890	5452
1989	3424	8303	10075	22032	9126	16079	7448	7270					11476
1990		7702	11195	5577	8747	6869	2170	6122	1053	3218			5850
1991		18713	10256	3110	5447	4721	6178	13494	8497	7220			8626
1992		24077	19083	22889	32649	17230	3894	189	5589	9099			14967
1993		19651	61742	37042	78058	85626	17109	9205	3924	5615			35330
1994		27912	15311	20272	27917	41190	15931	27747	26096	6975			23261
1995	51607	24233	82028	13251	33215	7443	27508		16475	592	39077	57353	25593
1981–1988	11719	7961	3152	7437	8524	12125	8327	9241	4701	5052	3927	6283	

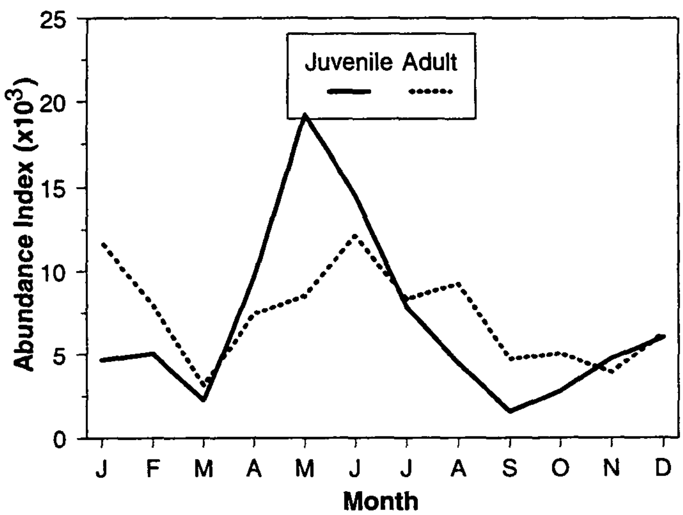

Figure 3 Seasonal abundance of juvenile and adult speckled sanddabs collected with the otter trawl. Data are mean abundance by month for 1981 through 1988.

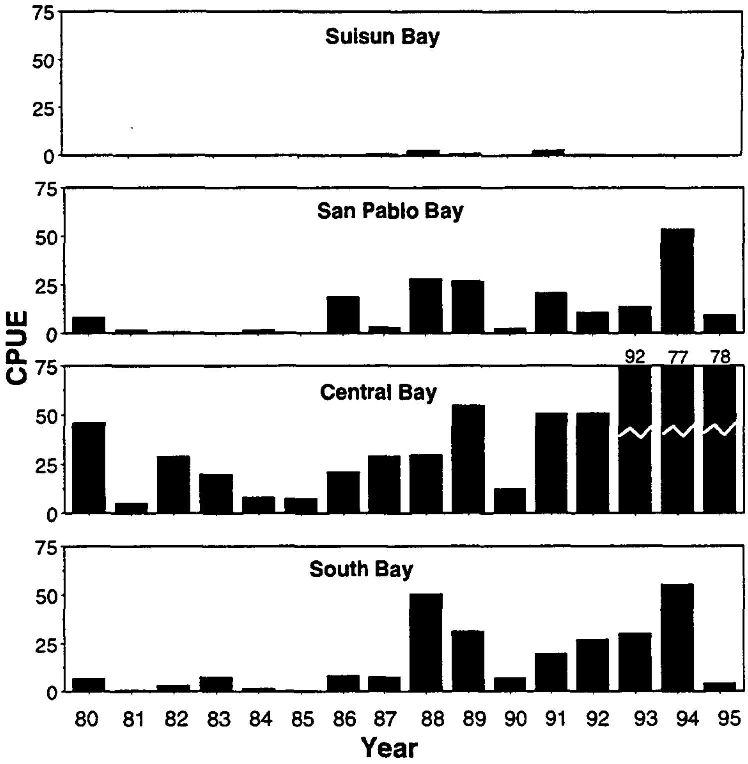

Figure 4 Annual distribution of juvenile speckled sanddabs collected with the otter trawl from 1980 to 1995. Data are mean CPUE by region for February to October.

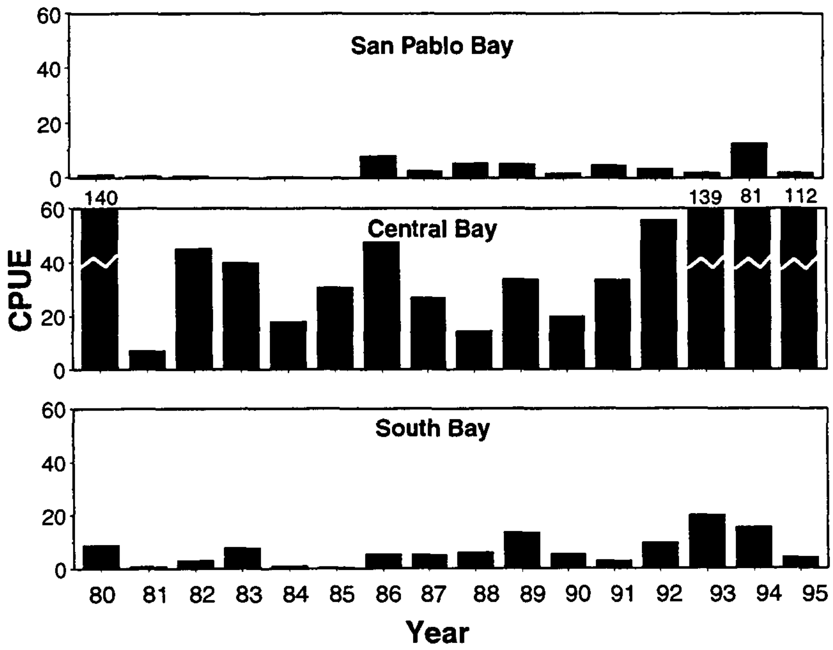

Figure 5 Annual distribution of adult speckled sanddabs collected with the otter trawl from 1980 to 1995. Data are mean CPUE by region for February to October.

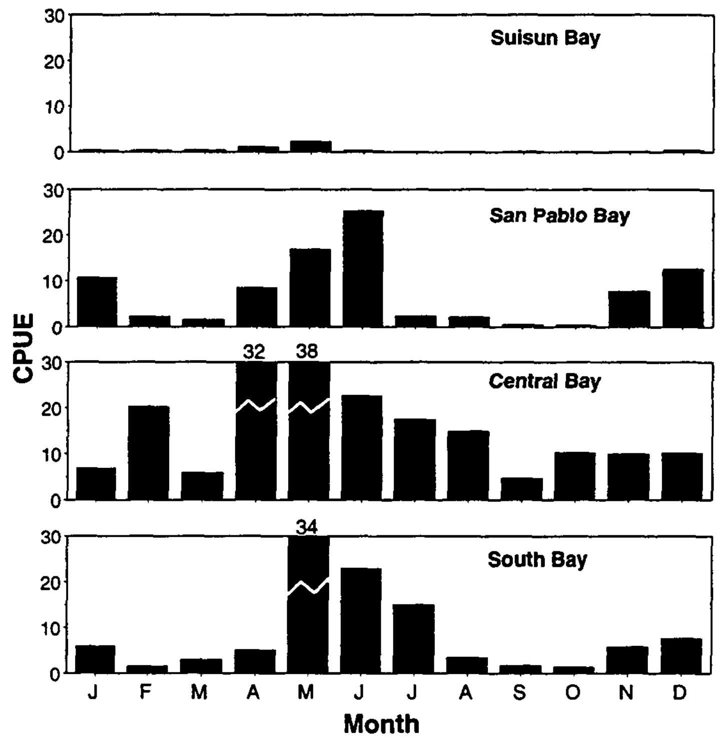

Figure 6 Seasonal distribution of juvenile speckled sanddabs collected with the otter trawl. Data are mean CPUE by region for 1981 to 1988.

Seasonal Distribution

Juvenile speckled sanddabs were most widely distributed (from South through Suisun bays) during their major immigration periods, November to January and April to June (Figure 6). During summer juveniles moved from Suisun, San Pablo, and South bays to Central Bay. A similar migration occurred in February and March.

Adult speckled sanddab CPUE increased in San Pablo and South bays during their summer and winter abundance peaks (Figure 7), a pattern similar to that of juveniles. However, most adult sanddabs appeared to remain in Central Bay all year.

During much of the year juvenile speckled sanddabs were almost equally distributed in both channel and shoal areas (Figure 8). From August to October, the warmest period of the year, more juveniles were in channels than on shoals. This pattern reversed in November and December, as the water cooled. Adult sanddabs were collected in higher numbers in channels than on shoals during most of the year (see Figure 8).

Both age groups were captured over wide salinity ranges: 4.9‰ to 34.4‰ for juveniles and 6.2‰ to 34.4‰ for adults. Both age groups inhabited primarily polyhaline and euhaline salinities, and were in the lowest and most variable salinities in March and April (Figure 9). The mean salinity for both groups increased from March or April to July and then remained >27‰ the rest of the year.

Juveniles were found at temperatures ranging from 8.2 to 22.4 °C and adults from 8.2 to 20.5 °C. Mean temperatures ranged from about 9.5 to 17.5 °C for both groups (Figure 10).

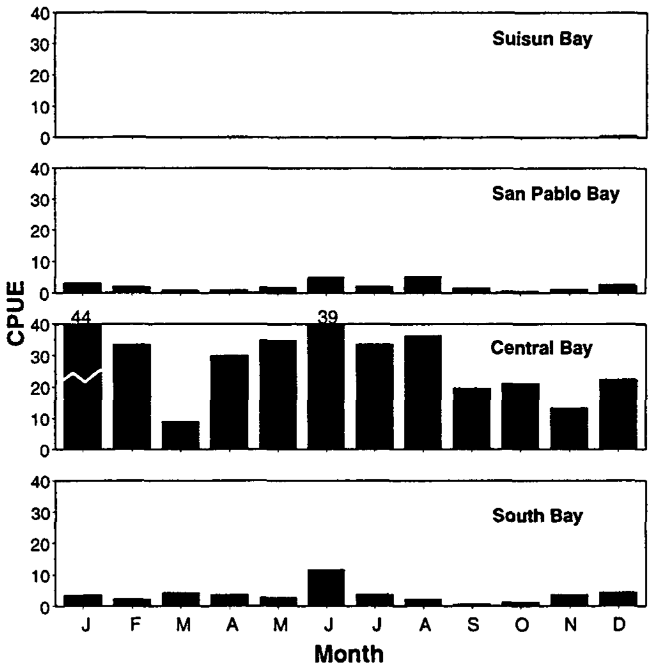

Figure 7 Seasonal distribution of adult speckled sanddabs collected with the otter trawl. Data are mean CPUE by region for 1981 to 1988.

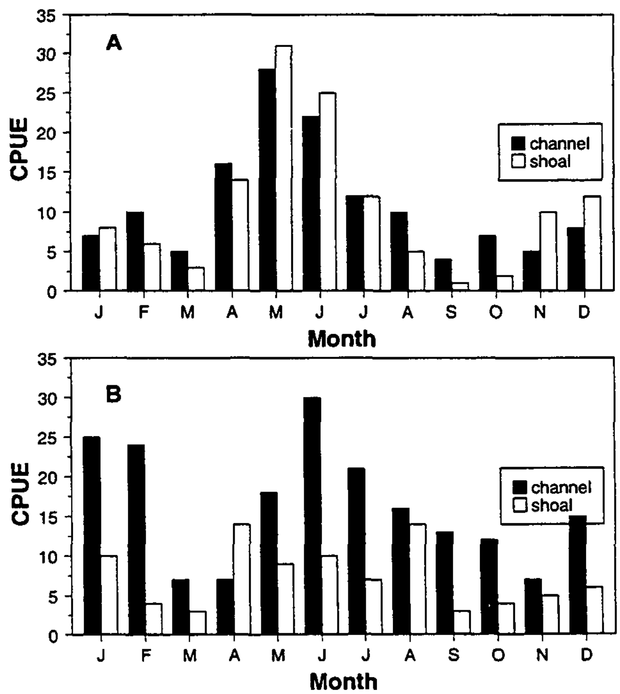

Figure 8 Depth distribution (shoal/channel) of (A) juvenile and (B) adult speckled sanddabs collected with the otter trawl. Data are mean CPUE by month and age group for 1981 to 1988.

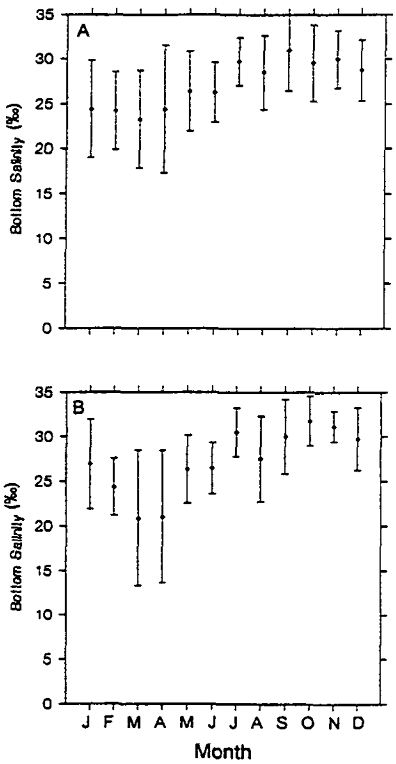

Figure 9 Salinity (‰) distributions of (A) juvenile and (B) adult speckled sanddabs collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity by month for 1981 to 1988.

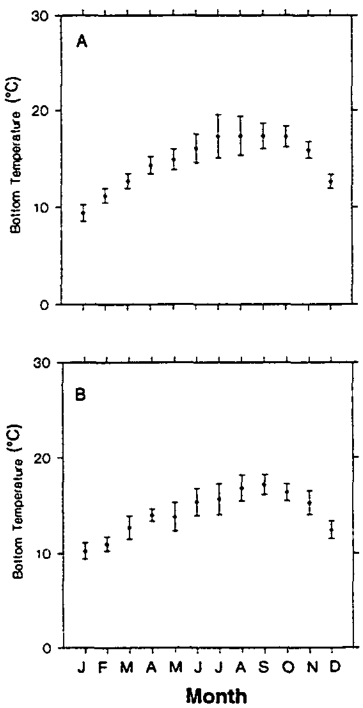

Figure 10 Temperature (°C) distributions of (A) juvenile and (B) adult speckled sanddabs collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom temperature by month for 1981 to 1988.

Discussion

The speckled sanddab used the estuary as a nursery and rearing area before migrating to the open coast to spawn. No spawning took place in the estuary, as no larvae were collected in it (see Table 1). The importance of the estuary as rearing habitat was shown by the high juvenile catch (see Table 1). The speckled sanddab is also abundant in other Pacific coast estuaries. It ranked among the top 4 species in trawl catches from lower Yaquina Bay, Oregon, and Elkhorn Slough, California (Pearcy and Myers 1974, Nybakken and others 1977). Larvae were rarely collected from these locations, supporting the conclusion that spawning takes place on the open coast, and metamorphosing larvae and juveniles enter estuaries.

Estuarine entry of juveniles took place all year, but occurred mainly from October to January and from April to June. These periods fit within a broad period of settlement observed for locally spawned fish. Otoliths from recently settled fish, read to back-calculate hatch and settlement dates, showed speckled sanddabs hatched along the coast from April to December and settled from October to May (M. Kendall, personal communication, see "Notes"). The monthly settlement pattern observed by Kendall was unimodal and so does not explain the bimodal entry pattern of juveniles.

Low salinity influenced juvenile distribution in the estuary from late winter to spring, and high water temperatures influenced it from summer to fall. Juvenile winter entry and adult winter to spring rearing appeared to be inhibited by reduced salinity caused by high outflows. Both juvenile and adult abundance indices were at seasonal minima in March, coincident with the seasonal salinity minimum (compare Figure 3 with Figures 1, 2, and 3 in the Salinity and Temperature chapter). During the drought years, juveniles extended well upstream into both San Pablo and Suisun bays, but during the high outflow years 1982 and 1983 none were captured in either bay. In northern estuaries, speckled sanddabs were primarily associated with marine influenced areas and channel bottoms, and were most abundant in May and June after river flows had subsided (Pearcy and Myers 1974, Bottom and others 1984). During late spring and summer, speckled sanddabs moved toward Central Bay and into deeper and cooler water from Suisun, San Pablo, and South bays; a reverse movement was observed in fall and early winter before salinity declined (compare Figures 6 through 8). In both lab and field observations, Ehrlich and others (1979) found higher abundance of speckled sanddabs at 8 to 13 °C, and argued that a significant negative correlation between field occurrence and temperature was evidence that temperature limited use of shallow King Harbor in summer and fall. Similarly, Ford (1965) found significant negative correlations between sanddab abundance and bottom temperatures for both juveniles and adults, though juveniles did not respond as strongly as adults. Juveniles appear less constrained by temperature and more likely to inhabit warmer, shallower water than adults.

In recent years, the speckled sanddab has become the most numerous flatfish in the estuary (see Appendix C, otter trawl annual catch). Like many other flatfish whose range is primarily south of the estuary (for example, California halibut, diamond turbot, and California tonguefish), speckled sanddab abundance increased through the late 1980s and early 1990s. During the drought it benefited from higher estuarine salinity and expanded its range upstream. Abundance continued to increase in 1993, even though moderate outflow reduced upstream habitat in winter and spring. Since spawning and larval rearing take place outside the estuary, oceanic conditions were probably responsible for the increase.

California Halibut

Introduction

The California halibut, *Paralichthys californicus*, ranges from Magdalena Bay, Baja California, to the Quillayute River, Washington (Miller and Lea 1972). It occurs from the surface to 185 m (Haaker 1975). It is an important species in both commercial and recreational fisheries of central and southern California (Kramer and Sunada 1992). In San Francisco Bay, the California halibut has supported a strong recreational and commercial passenger fishing vessel fishery since the mid-1980s.

Based upon distribution of larvae, spawning occurs in shallow coastal water from Magdalena Bay northward to about San Francisco Bay (Frey 1971, Ahlstrom and Moser 1975, Haaker 1975, Plummer and others 1983) from February to August (Fitch and Lavenberg 1971, Frey 1971, Feder and others 1974). Newly hatched larvae measure about 2.0 mm TL (Wang 1986) and are pelagic. Recently metamorphosed fish 8 to 12 mm standard length (SL), are between 20 and 29 days old (Allen 1988).

In southern California, newly settled halibut are found primarily in shallow water marine habitats (Allen 1988, Allen and Herbinson 1990, Kramer 1990a, Kramer 1991a). These authors state that virtually all young-of-the-year halibut move into bays before or soon after settlement, and that bays and other protected coastal areas are crucial nursery areas. Young halibut remain in shallow water embayments until they reach 150 to 200 mm SL, then migrate to the open coast (Haaker 1975, Kramer 1990a, Kramer 1991a). California halibut off the northern San Diego County coast are found in deeper water as they grow (Plummer and others 1983, Kramer 1990b). Males grow slower than females and mature at a length of about 200 mm SL, whereas, females mature at about 375 mm (Haaker 1975). All males are mature at 320 mm TL and all females at 590 mm TL (Love and Brooks 1990). They reach a maximum length of 1,525 mm TL (Miller and Lea 1972). The minimum size for the recreational fishery is 559 mm TL.

Methods

I examined length-frequency histograms to separate age groups. These histograms were derived by combining beach seine data from 1981 to 1986 with otter trawl data from 1981 to 1988. A cutoff length of 200 mm TL was used to separate age–0 and age–1+ fish in all months. Although somewhat subjective, 200 mm corresponds to the upper end of a size range poorly sampled in the estuary and was a reasonable approximation of the minimum size of age–1 halibut (Pattison and McAllister 1990). Standard length (SL) data from the literature were converted to total lengths (TL) with the following equation: $TL = 1.196 \times SL$ (Kramer 1990a).

Larval abundance and distribution analyses were based on the plankton net catches. Larvae were separated into stages based upon the presence (yolk sac larvae) or absence (post-yolk sac larvae) of yolk, and for post-yolk sac larvae into those <8 mm and those $\geq$8 mm (transforming larvae) (compare to Gadomski and Caddell 1991). For otter trawl caught fish, the 200 mm cutoff identified age–0 fish by year of capture rather than year of hatching, and may have included a sizeable number of age–1 fish. Except for the annual beach seine catch of age–0 fish, abundance and distribution analyses were based on otter trawl data only. Annual abundance and distribution indices for both age groups were based on a February to October sampling period. Seasonal abundance, distribution and channel-shoal comparisons for both age groups were based on 1981 through 1988 data. Salinity and temperature statistics were based upon bottom measurements taken during otter trawl sampling and weighted by CPUE for each life stage. Since few age–0 fish were taken with the otter trawl between 1981 and 1988, salinity and temperature statistics were calculated for all months combined. Monthly salinity and temperature statistics were calculated for age–1+ fish.

Results

Catch and Length Analyses

We captured 27 California halibut ranging from 40 to 173 mm TL with the beach seine and 590 halibut from 47 to 1,130 mm TL with the otter trawl (Figure 11). Based on 1981 to 1988 sampling, age–0 fish (<200 mm) were collected from November to the following June, and represented about 20% of the combined otter trawl and beach seine catch (see Figure 11). Of the age–0 fish, 75% (n = 36) were collected by beach seining, including all but 3 fish <100 mm TL. Only 10 fish between 100 and 200 mm TL were collected by both gear types. Almost 60% of the halibut caught in the otter trawl were 200 to 500 mm, with another 20% ≥500 mm TL (see Figure 11). Most halibut mature at or before 500 mm TL (Love and Brooks 1990), indicating that mature fish used the estuary.

Abundance and Distribution of Larvae

Seventy-four California halibut larvae were collected from 1980 to 1989 (Table 4); 59% of these were caught in 1983. Larvae were caught from South Bay to Suisun Bay but 78% were collected in Central Bay (see Table 4). Larvae were collected all year, except for April, June, and August (Table 5). Peak catches (78%) occurred from September to November (see Table 5) during or immediately after annual peaks in estuarine and coastal water temperatures (see Salinity and Temperature chapter, Figure 12). Pre-settlement (transforming) larvae were caught only from September to December.

Abundance and Distribution of Age–0 and Older Fish

Annual Abundance

Age–0 California halibut were collected with the beach seine in only 4 years: 1983, 1984, 1985, and 1986. Age–0 fish were rarely caught with the otter trawl in the estuary before 1991, occurring only in 1982, 1984, and 1985 (Figure 12, Table 6). Their abundance increased sharply after 1990 to a peak in 1993, then declined to 1995. Similarly, age–1+fish were not abundant during the early 1980s. But their abundance increased in the middle to late 1980s to a minor mode in 1987, declined in 1988 and 1989, increased to a major mode in 1993, then declined again (see Figure 12, Table 7). The 1986–1987 peak in age–1+ abundance occurred after local recruitment (that is, the capture of age–0 fish) was observed, whereas the 1993 peak occurred in the same year as the peak in age–0 abundance. From 1991 to 1995 both groups had similar abundance patterns.

Seasonal Abundance

Age–0 California halibut were first collected with the beach seine in November (see Figure 11) and in the otter trawl in December (Figure 13, see Table 6). These dates corresponded well with the peak of larval settlement in September and October (see Table 5). Age–0 fish were caught sporadically to the following June. After 1991, age–0 fish were caught regularly during the February to October sampling period (see Table 6).

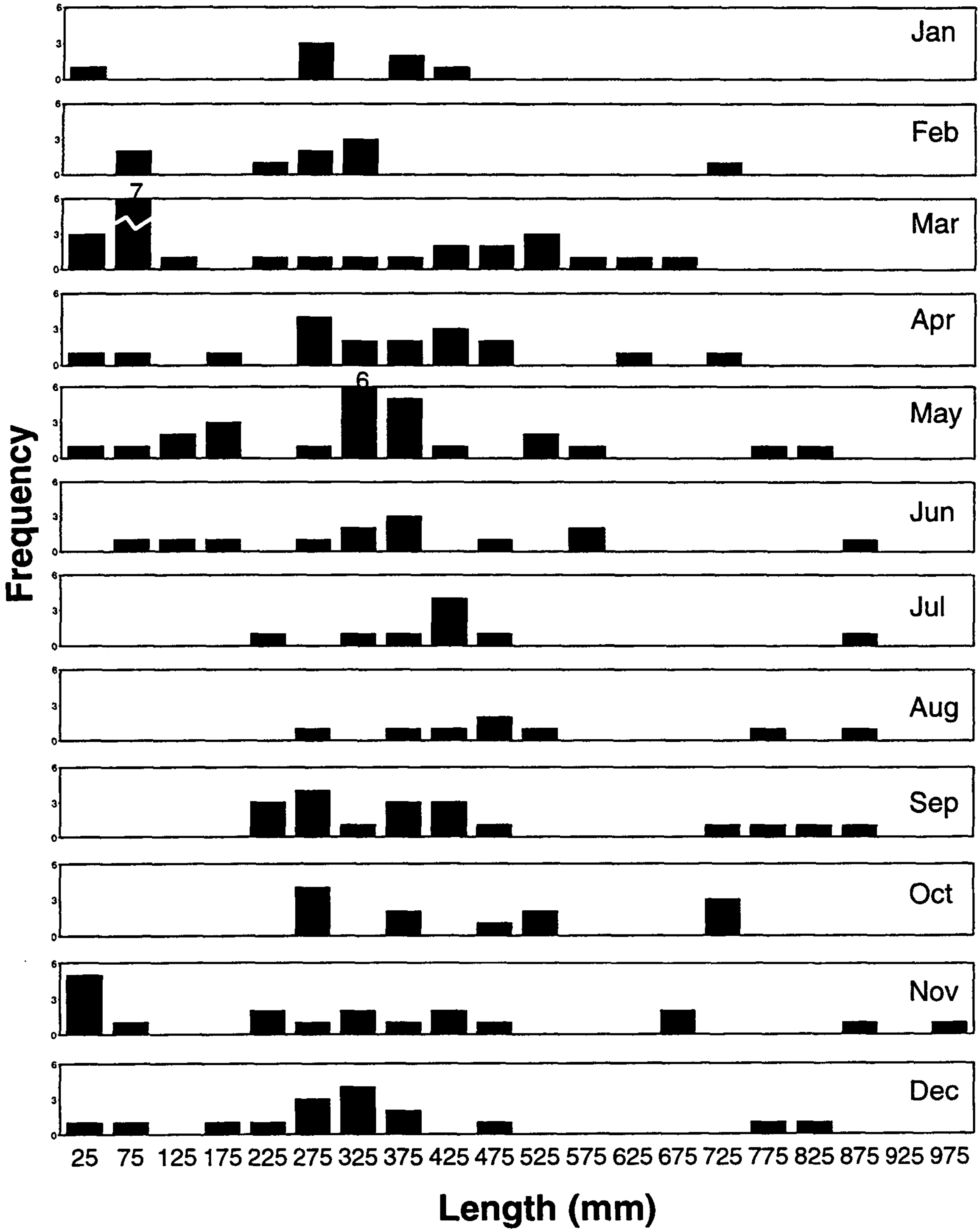

Figure 11 Length frequency (mm TL) by month of California halibut collected with the beach seine and otter trawl for 1981 to 1988. One 1,035 mm fish captured in October is not shown.

Table 4 Annual abundance (total catch) and distribution of larval California halibut collected by the plankton net from 1980 to 1989. Only the months of January through May were sampled in 1989. None were collected in the west delta.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*Total Catch*
1980	1	1	0	0	2
1981	0	1	0	0	1
1982	0	1	0	0	1
1983	2	40	2	0	44
1984	0	8	0	0	8
1985	1	5	1	0	7
1986	3	0	2	0	6
1987	0	1	0	0	1
1988	0	1	1	2	4
1989	0	0	0	0	0
Total	7	58	7	2	74

Table 5 Seasonal abundance (catch) of larval California halibut by stage captured in the plankton net from 1980 to 1989

Month	*Yolk Sac*	*Post Yolk Sac*	*Pre-settlement*	*Total*
Jan	0	1	0	1
Feb	0	1	0	1
Mar	0	2	0	2
Apr	0	0	0	0
May	0	1	0	1
Jun	0	0	0	0
Jul	4	3	0	7
Aug	0	0	0	0
Sep	0	7	7	14
Oct	2	23	6	31
Nov	2	10	1	13
Dec	0	3	1	4
Total	8	51	15	74

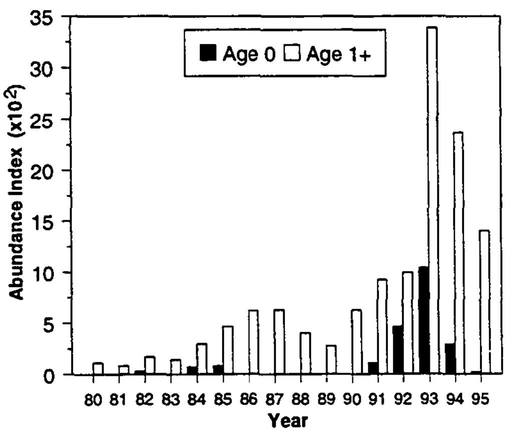

Figure 12 Annual abundance of age–0 and age–1+ California halibut collected with the otter trawl from 1980 to 1995. Data are the means of February to October monthly indices.

Table 6 Monthly abundance of age–0 California halibut captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	309	0	0	0	0	0	0	0	34
1983	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	438	250	0	0	0	0	0	0	76
1985	0	563	0	0	221	0	0	0	0	0	0	154	87
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0					0
1990		0	0	0	0	0	0	0	0	0			0
1991		384	473	0	0	173	0	0	0	0			114
1992		0	0	344	0	0	0	876	723	2270			468
1993		2139	4978	1171	138	480	154	0	0	344			1045
1994		0	0	0	297	250	0	576	1353	219			299
1995	0	192	0	0	0	0	0		0	0	0	281	24
1981–1988	0	70	0	0	121	31	0	0	0	0	0	19	

Table 7 Monthly abundance of age–1+ California halibut captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	135	362	377	189	0	0	0	0	0	250	118
1981	0	162	154	322	0	0	155	0	0	0	552	594	88
1982	281	313	278	0	559	219	0	0	0	185	219	0	173
1983	0	0	0	0	297	281	216	379	162	0	243	250	148
1984	0	250	243	281	219	250	0	219	1248	0	625	1028	301
1985	408	365	610	837	326	284	189	243	590	783	514	316	470
1986	271	97	250	250	1874	1220	381	250	352	919	652	0	621
1987	162	0	1347	1190	135	0	521	487	1362	625	297	737	630
1988	0	216	408	714	250	0	586	460	710	297	0	281	405
1989	0	0	985	270	0	216	0	480					279
1990		487	1082	662	768	250	0	784	1213	439			632
1991		947	895	838	1173	525	2138	281	909	633			927
1992		953	730	1164	493	1233	0	489	1345	2548			995
1993		2904	3822	3944	905	5811	5453	5514	748	1420			3391
1994		2513	2156	2451	1398	2279	1478	5478	3317	270			2371
1995	677	1521	509	1580	1511	1812	2554		1215	540	2319	1323	1405
1981–1988	140	175	411	449	458	282	256	255	553	351	388	401	

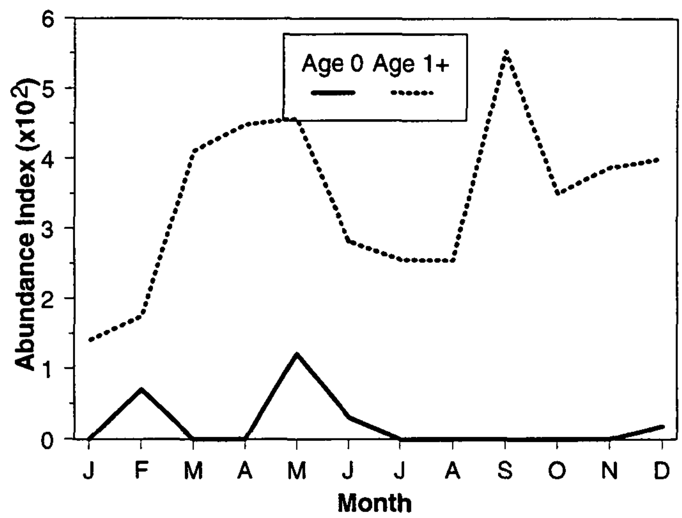

Figure 13 Seasonal abundance of age–0 and age–1+ California halibut collected with the otter trawl. Data are mean abundance by month for 1981 to 1988.

Age–1+ California halibut were captured in the estuary all year, but were most abundant during March to May and September to December (see Figure 13, see Table 7). But this pattern was based upon the catch of relatively few fish and may not be representative of the entire population. As abundance increased in the early 1990s, some shifts in the timing of peak abundance occurred. In 1993, age–1+ abundance peaked in June, July and August, months that had low abundance from 1981 to 1988 (see Table 7).

Annual Distribution

Age–0 California halibut were caught in all regions, but CPUE was highest in South and San Pablo bays; they were rare in Suisun Bay and the west delta (Figure 14). Age–1+ fish were also collected from all regions, and were also rare upstream from San Pablo Bay (Figure 15). Unlike age–0 fish, age–1+ CPUE was highest in most years in Central Bay. As annual abundance increased from 1990 to 1993, densities in South and San Pablo bays increased until they were equivalent to or higher than those of Central Bay (see Figure 15). This pattern reversed in 1994 and 1995.

Seasonal Distribution

Data for age–0 California halibut from 1981 to 1988 were not sufficient to describe seasonal distribution.

Age–1+ California halibut concentrated in Central Bay, except from December to February when they were primarily in South Bay (Figure 16). They entered Suisun Bay only in February and never reached the west delta during the 1981 to 1988 period.

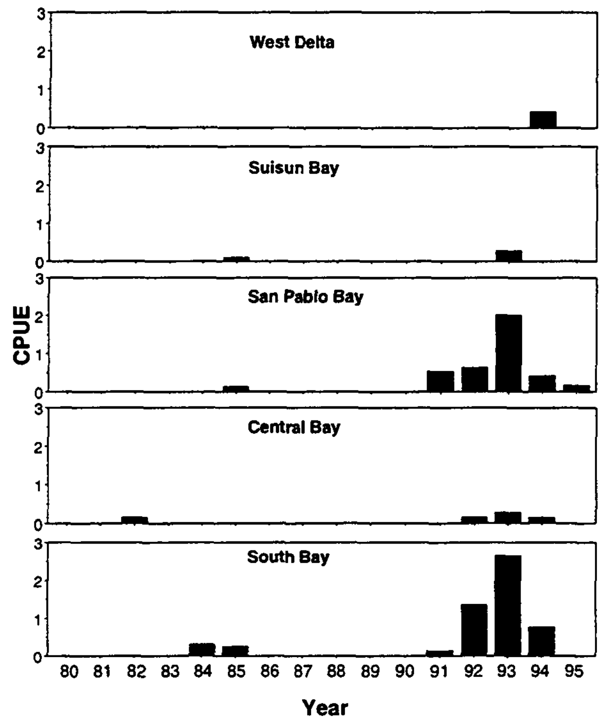

Figure 14 Annual distribution of age–0 California halibut collected with the otter trawl for 1980 to 1995. Data are mean February to October CPUE by region.

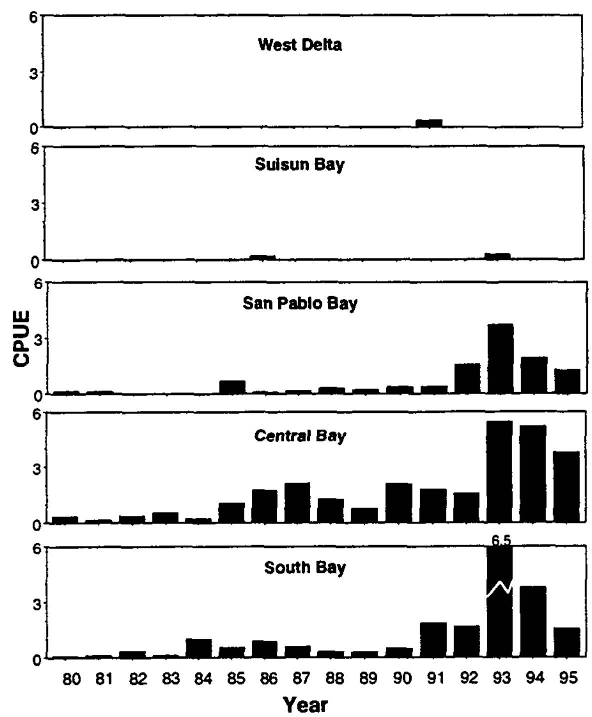

Figure 15 Annual distribution of age–1+ California halibut collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region.

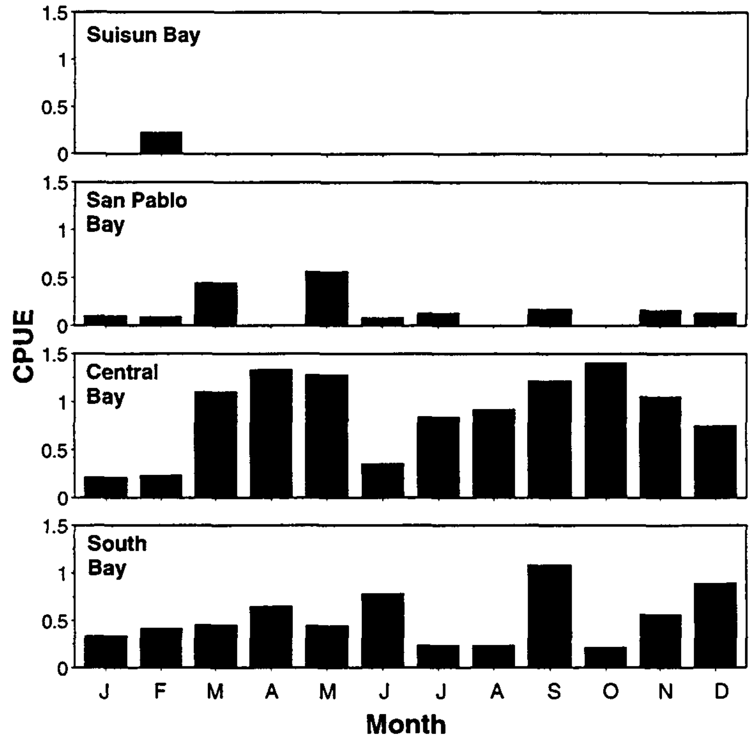

Figure 16 Seasonal distribution of age–1+ California halibut collected with the otter trawl. Data are mean CPUE by month and region from 1981 to 1988.

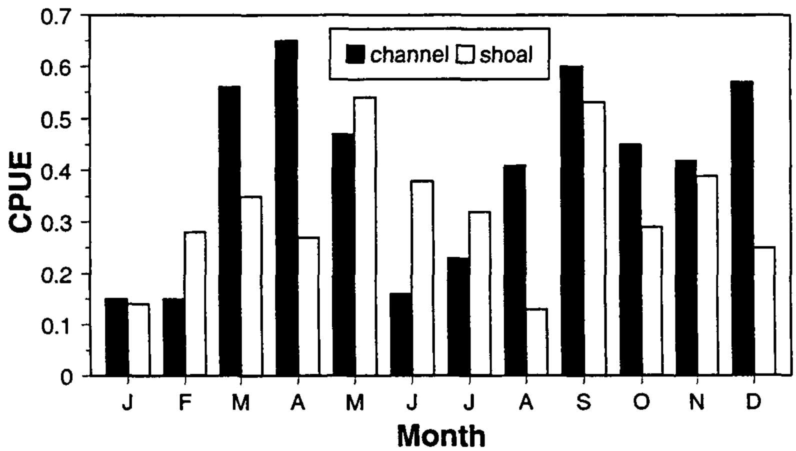

Figure 17 Depth distribution (channel/shoal) of age–1+ California halibut collected with the otter trawl from 1981 to 1988

Age–0 California halibut were 3 times as numerous in shoal areas as in channels, based on 1981 to 1988 data (overall channel CPUE = 0.01, overall shoal CPUE = 0.03). When 1980 to 1995 data were combined, this ratio increased to 7 to 1 in favor of shoals (overall channel CPUE = 0.03, overall shoal CPUE = 0.22). The channel to shoal ratio of age–1+ fish was close to 1:1 on an annual basis, but shoal use was slightly higher from May to July, and channel use was usually slightly higher the rest of the year (Figure 17).

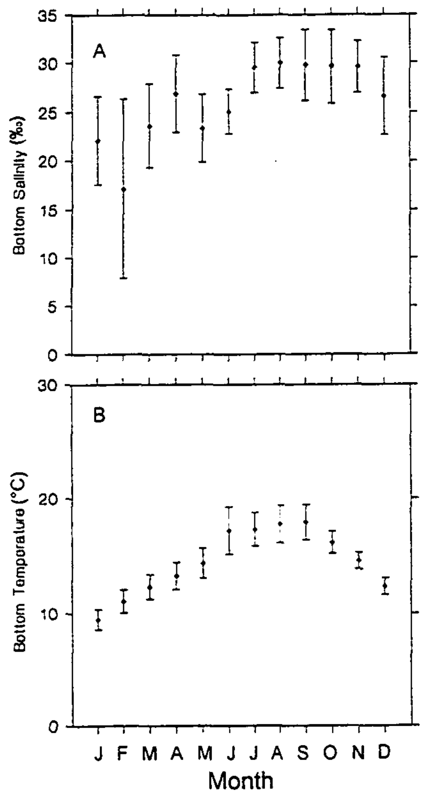

Figure 18 Salinity (‰) and temperature (°C) distributions of age–1+ California halibut collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

Data for age–0 California halibut were not sufficient to describe monthly salinity or temperature distributions, but otter trawl data for all months combined showed that age–0 fish were caught at 9.6‰ to 27.5‰, $\bar{\chi}$ = 21.9‰, and from 9.3 to 21.6 °C, $\bar{\chi}$ = 14.0 °C. Age–0 fish captured with the beach seine were found in higher salinity and temperature: 15.1‰ to 32.4‰, $\bar{\chi}$ = 24.6‰, and 9.5 to 25 °C, $\bar{\chi}$ = 16.9 °C. The higher beach seine temperatures were partially attributed to the high overall catch at the Hunter's Point site, which receives thermal effluent.

Age–1+ California halibut had a much broader salinity range than age–0 fish; they were taken from 1.7‰ to 34.3‰. The fish collected at 1.7‰ came from Suisun Bay in February 1986, after salinity dropped sharply from about 15‰ in January. From January to May, no age–1+ fish were caught at <14‰ and from June to December none were caught at <20‰. From July to November, the age–1+ salinity distribution stabilized at monthly means from 29‰ to 30‰ (Figure 18). Thus, most age–1+ fish were collected within the polyhaline range throughout the year.

Age–1+ fish were collected from 8.5 to 21.6 °C, similar to age–0 fish. Mean temperatures for age–1+ halibut ranged from 17 to 18 °C from June to September (see Figure 18).

Discussion

Although all life stages of the California halibut, except eggs, were collected in the estuary, age–0 fish were uncommon until the 1990s. The absence of juveniles was attributed to poor local recruitment and to limited sampling of their shallow water habitat.

San Francisco Bay is considered to be at the northern edge of the California halibut spawning range based upon the distribution of larvae (Ahlstrom and Moser 1975, Moser and Watson 1990). This suggests a link between spawning and water temperature. Laboratory observations indicate that both spawning and recruitment may be controlled by temperature. Successful spawning in the laboratory started between 15.0 and 16.5 °C (Caddell and others 1990). Although halibut eggs hatched from 12 to 20 °C, only about 3% of the larvae survived to 17 days at 12 °C, and only 33% survived to 17 days at 16 °C (Gadomski and Caddell 1991). Survival of older larvae improved with increasing temperatures. If similar temperatures were necessary for egg and larval survival in the wild, survival would have been low in the ocean off San Francisco Bay during most years, as sea surface temperatures ≥15 °C were rare (see Salinity and Temperature chapter, Figure 11).

The first substantial collections of larvae and small juveniles (which are evidence of local spawning and recruitment) came in fall 1983 and lasted until spring 1984. These collections appeared to be associated with elevated coastal ocean temperatures. From June to September 1983, average monthly sea surface temperatures for the Gulf of the Farallones increased from 11.5 to 16.3 °C and remained about 15 °C through November (see Salinity and Temperature chapter, Figure 11). From September to November 1983, a record 44 halibut larvae were collected (see Table 4), followed in early 1984 by collections of age–0 fish in the beach seine and otter trawl. However, not all periods of high water temperature resulted in evidence of local recruitment, and in some years minor recruitment was observed at low water temperatures. Larvae and age–0 fish were collected annually from 1984 to 1986 even though temperatures were never exceptionally high. In fall 1987, sea surface temperatures were again >14 °C, but plankton sampling showed little evidence of local spawning; only 1 larva and no age–0 fish were caught by the otter trawl in late 1987 and late 1988. Warm water periods during fall in 1990, 1991, 1992, and 1993 (including warm water through most of 1992) probably led to relatively high age–0 abundance from 1991 to 1994 (see Figure 12). Thus, some but not all recruitment was associated with warmer than normal fall sea surface temperatures and in at least 1 year, 1987, warmer than normal conditions did not result in detectable recruitment to the estuary.

Limited sampling of inshore areas may have hindered our ability to detect local recruitment and follow trends in age–0 abundance, especially after 1986 when beach seine sampling ended. In this estuary and near San Diego, age–0 fish abundance was highest in shoreline habitats (Plummer and others 1983, Kramer 1990b). Termination of beach seining eliminated the most effective gear for collecting small age–0 fish, and this termination occurred before the elevated sea surface temperatures in fall 1987 and in several years during the early 1990s. Yet even with the beach seine, it was possible to miss evidence of recruitment. Sampling in the estuary at the Hunter's Point station and along the southern California coast indicated that young halibut settle and remain in the warmest habitats available. There was a significant positive relationship between temperature and settlement and the subsequent distribution of age–0 halibut (Allen and others 1990). So, age–0 fish may have been attracted to unsampled areas such as locations receiving thermal effluent and warm South Bay sloughs. Moreover, most beach seine sites faced the open estuary and though protected from ocean swells, they were not as protected as sloughs or many of the inner harbors. Fully protected areas attract higher densities of age–0 halibut than semi-protected areas (Allen and others 1990). So, when recruitment was low it was possible to miss it. At higher levels of recruitment some age–0 fish might stray from optimal habitats into deeper water. During the early 1990s, the relatively high catches of age–0 fish in the otter trawl may have resulted from straying or from intraspecific competition for food or space forcing fish into deeper water. Due to the strong ontogenic change in depth observed for California halibut (Kramer 1990b), these otter trawl fish were believed to represent even larger numbers in inshore areas.

The increase in California halibut abundance in the estuary over the last 2 decades appears to have occurred as a result of a succession of warm water and El Niño years, each of which incrementally increased the local adult population. This increase was probably accomplished through a combination of northward movement of juveniles and adults along the coast and local recruitment. Information derived from tagging studies indicates that most fish did not move away from the release point (Haaker 1975, Tupen 1990, Domeier and Chun 1995). Of the fish that did move, equal numbers moved north and south. Larger fish (>500 mm TL) moved significantly farther than smaller fish, and those moving north traveled significantly farther and faster than those moving south (Domeier and Chun 1995). A northward movement of adult halibut was detected before abundance increased in the estuary. Between 1978 and 1983, commercial trawl catches off northern California increased 4 to 5 times before stabilizing from 1984 to 1986 at levels 2 to 3 times pre-1978 levels (Jow 1990). During winter 1977–1978, local recruitment may have increased halibut abundance in South Bay (Pearson 1989). The increase in commercially available adult halibut probably set the stage for local recruitment by dramatically increasing local fecundity. When local fecundity is relatively high even conditions leading to marginal egg and larval survival could result in some recruitment. Successful local recruitment led to increased age–1+ abundance in the estuary during the middle to late 1980s. Although age–1+ indices declined through 1989, this reflected the lack of additional strong year classes recruiting to the estuary and reduced catchability of previous year classes. A strong local sport fishery during this period indicated that large halibut were locally abundant. It was the fecundity of these fish that produced the local recruitment observed in the early 1990s.

Although both age groups of halibut were captured in all regions of the estuary, low salinity appeared to limit their upstream distribution. Fish were occasionally caught between 1.7‰ and 14‰ salinity, but only during winter and spring when sharp increases in outflow changed salinity rapidly. Halibut did not appear to select salinity <20‰.

Bays, estuaries, and other protected habitats are important, possibly critical nursery areas for halibut (Haaker 1975, Plummer and others 1983, Allen 1988, Allen and others 1990, Allen and Herbinson 1990, Hammann and Ramirez–Gonzalez 1990, Kramer 1990b, Kramer 1991a). Our data suggest that the San Francisco Estuary may also be an important nursery area, but that more extensive shallow water and shoreline sampling will be required to assess its importance.

English Sole

Introduction

The English sole, *Pleuronectes vetulus*, ranges from San Cristobal Bay, Baja California, northward to northwest Alaska (Miller and Lea 1972). It is distinguished from other flatfish by an eye being visible from the blind side. It is not commonly caught in the sport fishery, but in California's commercial trawl fishery, the English sole generally ranks 2nd in pounds landed behind the Dover sole (Pearson and Owen 1992). Mature fish are found between 18 and 305 m deep, but juveniles rear in intertidal and subtidal habitats in bays and estuaries (Toole 1980, Bayer 1981, Krygier and Pearcy 1986, Pearson and Owen 1992).

Spawning occurs in coastal waters from September through April (Budd 1940, Ketchen 1956, Jow 1969, Laroche and Richardson 1979), but primarily during January and February in California (Jow 1969). English sole larvae are dominant in the winter to early spring ichthyoplankton community, 1 to 28 km off the coast of Oregon (Richardson and Pearcy 1977).

Under laboratory conditions larvae hatch at 2.8 mm and survive best at 25‰ to 28‰ salinity, and 8 to 9 °C (Alderdice and Forrester 1968). Their pelagic period lasts 6 to 10 weeks based upon the difference between peak spawning and when transforming individuals appear in nursery areas (Ketchen 1956). Using otolith increments, Laroche and others (1982) found most larvae transformed in less than 70 days and the oldest at 74 days. Metamorphosis is generally complete at 20 mm SL (Ahlstrom and Moser 1975, Misitano 1976).

Few early-stage larvae are collected in estuaries or bays (Pearcy and Myers 1974, Misitano 1977); however, transforming larvae and young juveniles are very common in them (Ketchen 1956, Olson and Pratt 1973, Pearcy and Myers 1974, Misitano 1976, Toole 1980). Settlement occurs both on the open coast and in bays and estuaries (Krygier and Pearcy 1986, Gunderson and others 1990). A large proportion of English sole settling on the open coast rapidly migrate to bay and estuarine nursery areas (Ketchen 1956, Olson and Pratt 1973, Krygier and Pearcy 1986, Gunderson and others 1990).

English sole inhabit intertidal areas in northern bays and estuaries, but remain primarily in channels in southern ones (Toole 1980, Bayer 1981, Krygier and Pearcy 1986, Yoklavich and others 1991). Throughout their range, juveniles move to deeper water as they grow and continue to do so after they emigrate to the open coast (Day and Pearcy 1968, Toole 1980, Krygier and Pearcy 1986). Juveniles rear in bays or estuaries through their 1st summer, then emigrate to the open coast during fall or winter at 80 to 150 mm TL (Smith and Nitsos 1969, Olson and Pratt 1973, Misitano 1976, Krygier and Pearcy 1986, Gunderson and others 1990). Males reach sexual maturity at 2 years and 250 to 295 mm TL and females at 3 to 4 years (Ketchen 1956). Males mature as small as 210 mm and almost all are mature by 290 mm, whereas females began to mature at 260 mm and most are mature by 350 mm (Harry 1959). The English sole reaches a maximum length of approximately 570 mm (Miller and Lea 1972).

Methods

In the plankton net, English sole were categorized as yolk sac larvae, post-yolk sac larvae, and age–0 fish. Yolk sac (stage I, Misitano 1976) were distinguished from post-yolk sac larvae by the presence of yolk or an oil droplet. After yolk absorption, larvae were post-yolk sac (stages II to V, Misitano 1976) until eye migration was complete. In the beach seine and otter trawl catches, all fish were considered age–0 or older, but those <30 mm TL were defined as recently settled. Monthly cutoff lengths (the minimum size of age–1+ fish) used to separate age–0 from older fish were 65, 80, 95, 112, 123, 130, 138, 145, 150, 155, 160, and 165 mm TL for January to December. Length data for 1981 to 1988 from both the beach seine and the otter trawl were combined for length frequency analyses.

For larvae (yolk sac and post-yolk sac combined) and age–0 fish in the plankton net, annual abundance indices were calculated as mean of volume-weighted monthly indices for December to May, and labeled as the year beginning January 1. Seasonal abundance was calculated as the mean of monthly indices for 1981 to 1988. Annual distribution was calculated as mean January to May CPUE by region.

Otter trawl data were used for abundance and distribution analyses for age–0 and age–1+fish. Annual abundance indices were the means of the February to October monthly indices for age–0 and age–1+ fish. Beach seine and otter trawl CPUE data were used to examine channel and shoal distribution. Salinity and temperature distributions were developed for each age group as the monthly means ±1 standard deviation of the CPUE-weighted bottom measurement (that is, salinity or temperature) for 1981 to 1988.

Results

Length Analyses

In the plankton net, English sole larvae ranged from 2.5 to 22 mm TL and age–0 fish ranged from 18 to 50 mm TL. Those from the beach seine ranged from 19 to 162 mm TL, and from the otter trawl 16 to 334 mm TL (Figure 19). There was no sharp separation of age–0 fish from older individuals (age–1+), but cutoff lengths provided reasonably accurate separation. The age–1+ group was composed primarily of age–1 fish.

Recently settled English sole (<30 mm) were collected all year, but primarily from March through August. Several abrupt increases in catch indicated estuarine entry of different sized fish in different years. Thus, in March there was an increase in previously settled 50 to 80 mm fish; in April an increase in recently settled 20 to 40 mm fish; and in May 40 to 70 mm fish increased (see Figure 19). However, growth can not be assessed well from these data. By December, age–0 fish had reached a maximum length of about 160 mm. Age–1+ fish <160 mm remained in or returned to the estuary during the next winter and spring. Fish >180 mm were uncommonly caught and mature fish (>250 mm) were rarely caught (see Figure 19).

Abundance and Distribution of Larvae

Of the 429 larval English sole collected during the study, 293 (68%) were caught in 1982. Hence, the 1982 annual abundance index was an order of magnitude higher than in other years (Figure 20, Table 8). Abundance was also high in 1983 but low thereafter. No larvae were caught in 1984. In the plankton net, there was no apparent relationship between larval abundance and that of age–0 fish (see Figure 20).

The 1st English sole larvae of the year were caught in December (Figure 21, see Table 8). Their abundance increased rapidly until February and then declined to zero in June. Larvae were collected from South Bay to Suisun Bay in 1982, but their distribution was more restricted in other years when they were absent from either South or Suisun bay (Table 9).

Abundance and Distribution of Age–0 and Older Fish

Annual Abundance

Although there was no consistent trend in age–0 English sole abundance indices, year to year fluctuations were greater after 1989 (Figure 22, Table 10). These fluctuations reached an extreme in 1993 and 1994 when the lowest index followed the highest.

The abundance of age–1+ English sole was highest in 1980 (see Figure 22, Table 11). After a sharp drop in 1981, age–1+ abundance rose to another mode in 1984, then declined to a record low in 1987. Abundance fluctuated thereafter but remained well below 1980 to 1985 levels (with the exception of 1981).

Seasonal Abundance

Age–0 English sole were first collected in December and their abundance increased until May before declining to lower level in December (Figure 23, see Table 10). Thus, December abundance was sometimes composed of 2 year classes: those individuals of the present year class remaining in the estuary and a small proportion of early settling individuals of the next year class (see Figure 19). Abundance of age–1+ fish had a peak in January and then declined for the remainder of the year (see Figure 23, see Table 11). Abundance increased slightly from September to December when all sizes of age–1+ fish were collected again (see Figure 23).

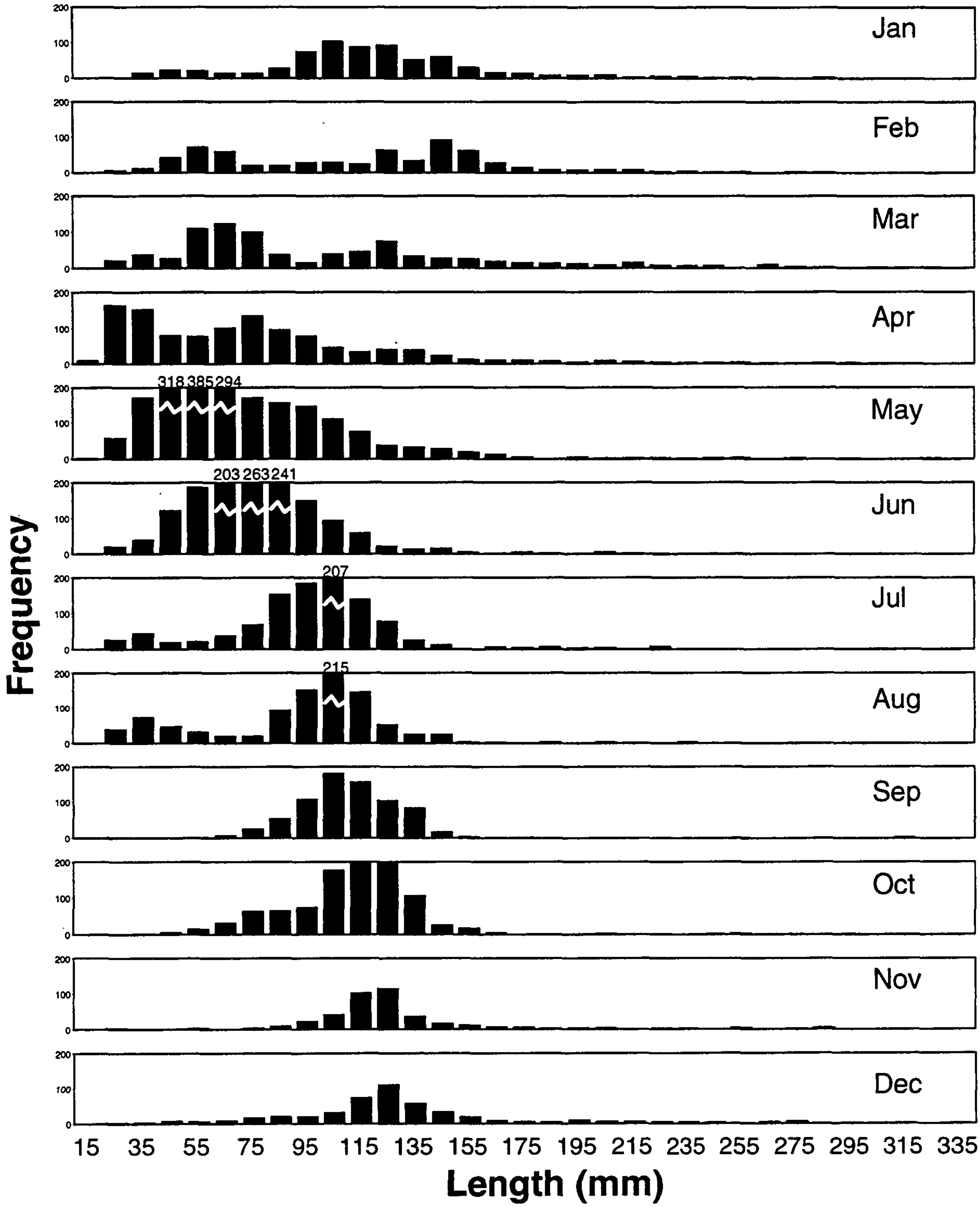

Figure 19 Length frequency (mm TL) by month of English sole collected with the beach seine and otter trawl from 1981 to 1988. Fish <30 mm were considered recently settled and those >250 mm were considered mature.

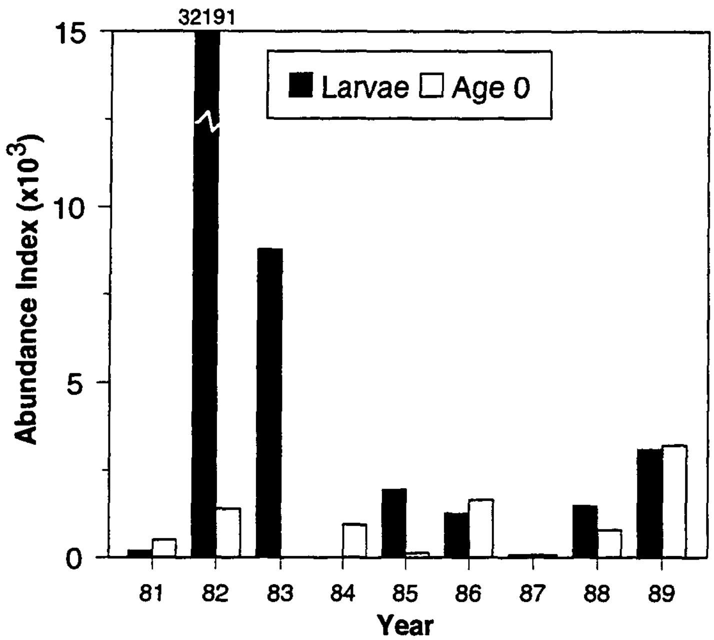

Figure 20 Annual abundance of larval and age–0 English sole from the plankton net from 1981 to 1989. Data are mean December to May abundance indices.

Table 8 Monthly abundance larval English sole captured in the plankton net from 1980 to 1989. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dec–May
1980		5372	27219	861	0	0	0	0	0	0	0	0	
1981	1074	0	0	0	0	0	0	0	0	0	0	0	179
1982	716	191353	1074	0	0	0	0	0	0	0	0	6921	32191
1983	5664	26502	7521	2149	3940	0	0	0	0	0	0	0	8783
1984	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	4698	5947	1074	0	0	0	0	0	0	0	0	1074	1953
1986	4656	0	753	1074	0	0	0	0	0	0	0	431	1260
1987	0	0	0	0	0	0	0	0	0	0	0	0	72
1988	0	8954	0	0	0	0	0	0	0	0	0	0	1492
1989	2938	11053	4613	0	0								3101
1981–1988	2101	29095	1303	403	493	0	0	0	0	0	0	1053	

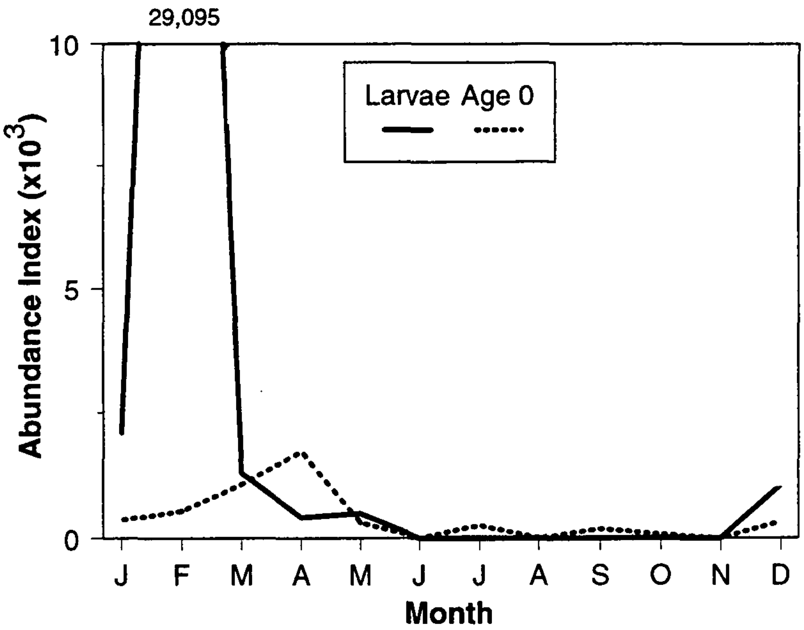

Figure 21 Seasonal abundance of larval and age–0 English sole from the plankton net. Data are mean monthly abundance indices for 1981 to 1988.

Table 9 Annual distribution of larval English sole collected by the plankton net. Data are mean January to May CPUE by region. None were collected in the west delta.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*
1980	0	2.8	0.3	0
1981	0	0.1	0	0
1982	0.4	9.8	11.6	0.4
1983	0.1	3.0	0.5	0
1984	0	0	0	0
1985	0	0.3	1.2	1.0
1986	0.1	0.4	0	0
1987	0	0	0	0
1988	0	0.5	0.5	0.1
1989	0.8	0.8	0.3	0
1980–1989	0.1	1.8	1.4	0.2

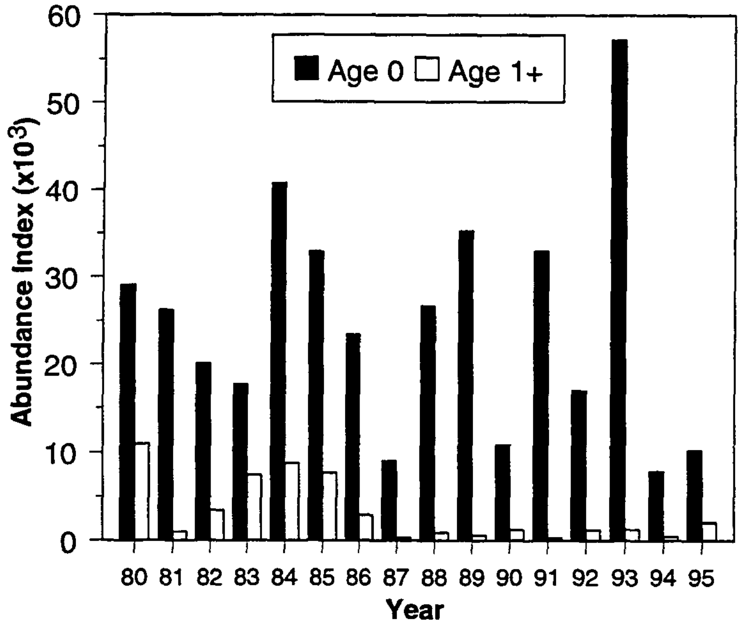

Figure 22 Annual abundance of age–0 and age–1+ English sole collected with the otter trawl from 1980 to 1995. Data are mean February to October abundance indices.

Table 10 Monthly abundance age–0 English sole captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		3393	2581	8725	39814	53935	81196	30376	14715	27097	20176	921	29092
1981	5094	17709	37521	33495	42697	21701	20147	40907	3222	18481	946	2228	26209
1982	1217	134	11303	35086	37879	42946	13062	22615	8483	9617	3670	5233	20125
1983	0	288	907	14757	9303	3590	42592	51111	752	36075	3674	14865	17708
1984	502	281	2164	10092	22474	109014	62839	16183	76690	67552	6611	16469	40810
1985	0	192	216	706	53821	27538	33516	81388	39458	60077	55951	40736	32990
1986	2266	12310	17206	19486	52563	37495	45034	12615	7845	6516	1301	1791	23452
1987	0	1379	3919	766	14712	15936	14226	8699	17203	4570	787	2353	9046
1988	563	423	3219	61116	112880	42836	15544	1541	1541	595	173	461	26633
1989	1503	13149	28383	60144	72336	27295	35940	9834					35297
1990		3985	10497	24536	30896	24002	562	1677	1617	0			10864
1991		68241	97181	60166	24231	20992	16877	6267	1028	2217			33022
1992		32820	49477	43735	16797	9298	779	0	0	0			16990
1993		1374	697	50330	180950	179547	77990	18114	3591	2163			57195
1994		0	1106	2932	6222	34457	9452	11193	4814	622			7866
1995	2372	2609	20445	13073	8663	27767	7496		2163	0	811	9308	10277
1981–1988	1205	4090	9557	21938	43291	37632	30870	29382	19399	25435	9139	10517	

Table 11 Monthly abundance age–1+ English sole captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		24896	16263	9659	34617	2548	8059	1055	550	1325	974	0	10997
1981	23909	1209	1425	805	1250	885	1823	773	162	649	487	595	998
1982	102019	1641	3227	2476	10347	6274	1360	2950	930	2040	2144	473	3472
1983	11219	17772	20868	21522	2704	1680	487	1812	0	433	0	1100	7475
1984	18013	12766	43985	9164	8894	1271	3110	0	0	0	676	1003	8799
1985	23142	55653	10222	1190	514	162	379	0	595	811	3029	4056	7725
1986	13119	3686	2930	6409	4762	2250	4165	359	656	1028	0	352	2916
1987	1890	687	663	162	628	0	0	0	487	595	325	4543	358
1988	4509	2294	2243	2329	784	622	0	0	162	0	0	0	937
1989	921	1484	1846	243	0	216	703	0					642
1990		5184	4706	1011	427	0	0	0	0	162			1277
1991		703	1614	381	0	0	0	0	0	568			363
1992		3575	4600	2228	715	216	0	0	0	0			1259
1993		1442	1970	4246	2574	1379	297	0	0	0			1323
1994		470	1231	1433	757	730	0	0	0	0			513
1995	0	216	3407	2433	250	8113	2299		216	0	649	0	2117
1981–1988	24728	11964	10695	5507	3735	1643	1416	737	374	695	833	1515	

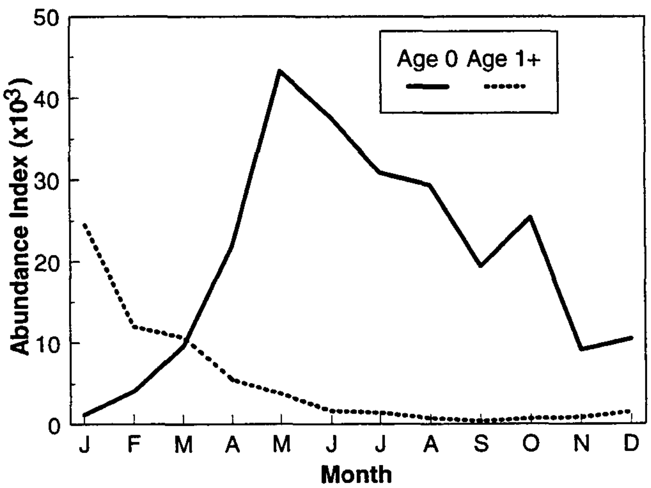

Figure 23 Seasonal abundance of age–0 and age–1+ English sole from the otter trawl. Data are mean monthly abundance indices for 1981 to 1988.

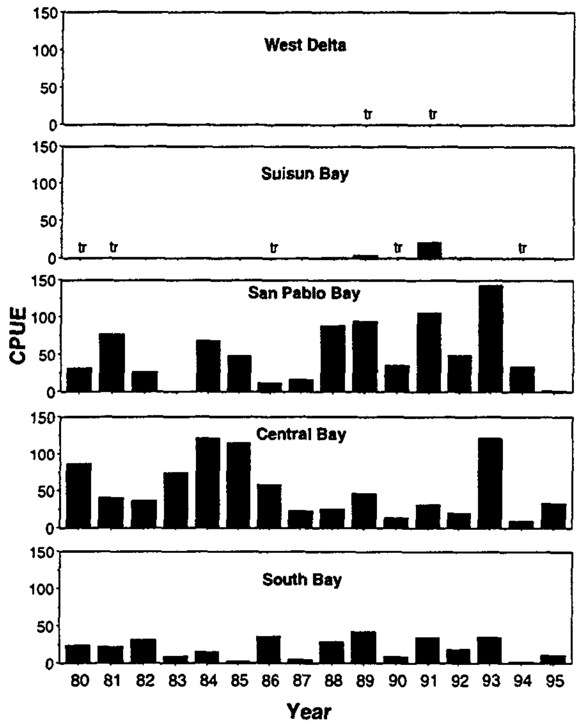

Figure 24 Annual distribution of age–0 English sole collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region. The letters "tr" indicate CPUE too low to plot.

Annual Distribution

Age–0 English sole were always present from South Bay to San Pablo Bay, were occasionally in Suisun Bay, but were rarely in the west delta and then only during the drought years 1989 and 1991 (Figure 24). Age–0 fish were concentrated in Central Bay from 1980 to 1987, except for 1981. From 1988 to 1994, during the drought, peak CPUE shifted into San Pablo Bay. However, in 1995, a high outflow year, peak CPUE was again in Central Bay.

Except for 1985, age–1+ English sole ranged from South to San Pablo bays and, in 1992, into Suisun Bay (Figure 25). Density was highest in Central Bay, except in 1989 and 1990.

Seasonal Distribution

Early settling age–0 English sole entered Central Bay in December and were not distinguished from the previous year class. They quickly migrated, so that from January to March CPUE increased more quickly in San Pablo and South bays than in Central Bay (Figure 26). Few age–0 fish moved into Suisun Bay and none were caught in the west delta. In all 3 lower bays, immigration continued and CPUE increased from January to May. Use of South and San Pablo bays remained high to June then declined rapidly as fish returned to Central Bay. CPUE in Central Bay peaked in July, remained high in August, and then declined as many age–0 fish left the estuary in fall.

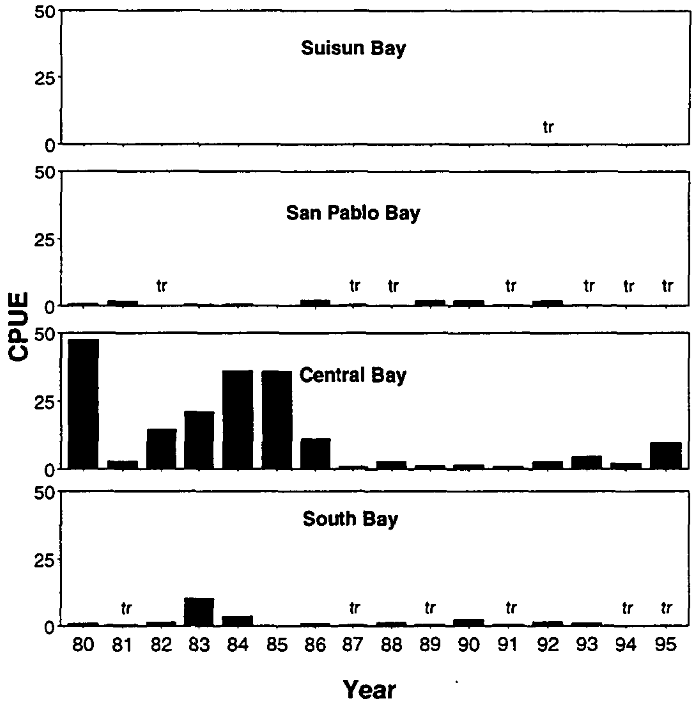

Figure 25 Annual distribution of age–1+ English sole collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region. The letters "tr" indicate CPUE too low to plot.

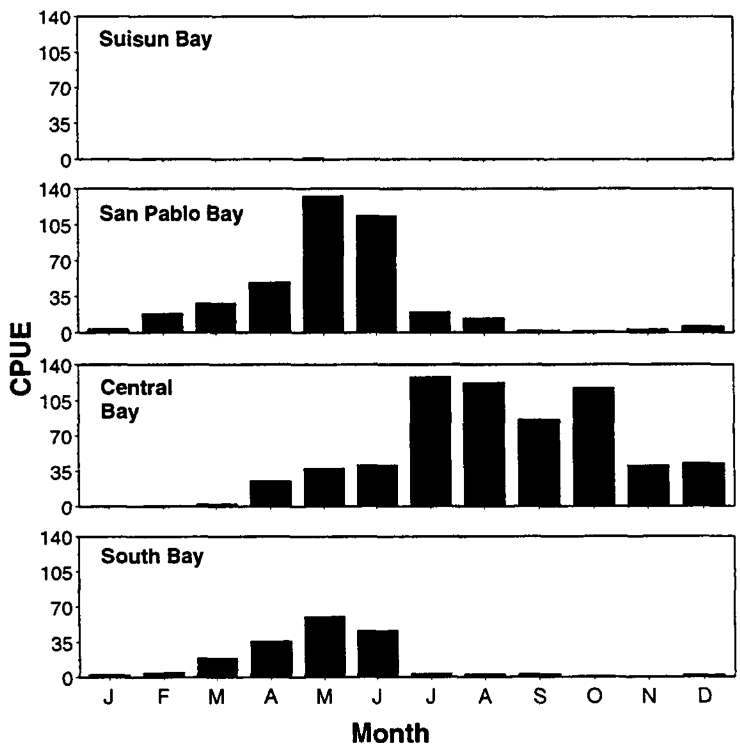

Figure 26 Seasonal distribution of age–0 English sole in the otter trawl. Data are mean CPUE by month and region for 1981 to 1988.

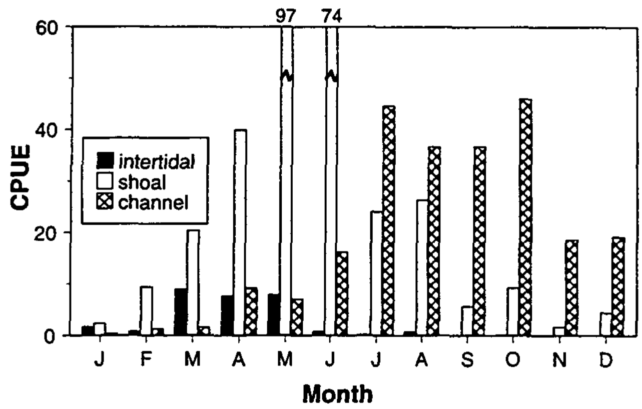

Figure 27 Depth distribution of age–0 English sole collected with the beach seine (intertidal) and the otter trawl (shoal and channel). Data are mean CPUE by month for 1981 to 1986 (beach seine) and for 1981 to 1988 (otter trawl).

Geographical movements of age–0 English sole were accompanied by shifts along depth, salinity, and temperature gradients. As age–0 fish entered the estuary in spring, they sought shallow subtidal and intertidal areas for rearing (Figure 27). Intertidal areas were used primarily from March to May; only a few fish were captured in them from June to October. Use of subtidal shoal areas peaked in May, then declined through September as channel use increased and remained higher than shoal use for the rest of the year.

The use of primarily shallow intertidal and subtidal habitats from February to April exposed age–0 English sole to mean salinities of 18‰ to 20‰ and mean temperatures of 11.8 to 15.0 °C. (Figure 28). Decreased outflow and movement to channels and Central Bay in summer put age–0 fish in average salinities of 30‰ (see Figure 28). From July through the end of the year, mean salinity ranged from 28.9‰ to 32.2‰. Mean temperature rose steadily from about 10 °C in January to a peak of 17 °C in June remained stable to September and then declined (see Figure 28).

Age–1+ English sole were most widely distributed in January from South Bay to Suisun Bay (Figure 29). From about January through July, CPUE declined in all regions as fish emigrated to the open coast. During the remainder of the summer and fall age–1+ fish were rarely caught outside Central Bay, and catch in Central Bay declined to September before increasing again until December. By December, a few were being caught again in South and San Pablo bays.

Age–1+ English sole were strongly channel oriented during the January to April period when most remained in the estuary (Figure 30). Only in May did shoal CPUE surpass that of the channels. Intertidal CPUE was very low from February to May and zero during the remainder of the year. By June, most age–1+ fish had left the shoal and intertidal areas (see Figure 30).

Age–1+ English sole were strongly concentrated in channels and in Central Bay, and, therefore were not exposed to the low January to May salinity and rapidly warming temperatures faced by age–0 fish. However, they inhabited areas of distinctly lower salinity during high outflow months: mean salinity ranged from 22.2‰ to 25.8‰ between January and May (Figure 31). From April through July mean salinity increased rapidly to 31.4‰, then similar to age–0 fish, the distributions were stable through the end of the year, with means between 28.2‰ and 31.4‰ (see Figure 31). As estuarine water temperatures warmed from January to June, the age–1+ fish that remained were found in progressively warmer water; their mean temperature rose from 10.4 to 15 °C (see Figure 31). After June, the few remaining age–1+ fish inhabited even warmer water through September, when their mean temperature reached a peak of 16.7 °C, then declined as estuary temperatures did.

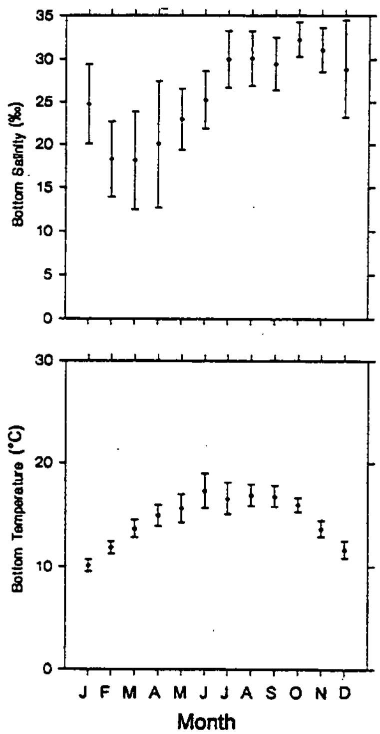

Figure 28 Salinity (‰) and temperature (°C) distributions of age–0 English sole collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

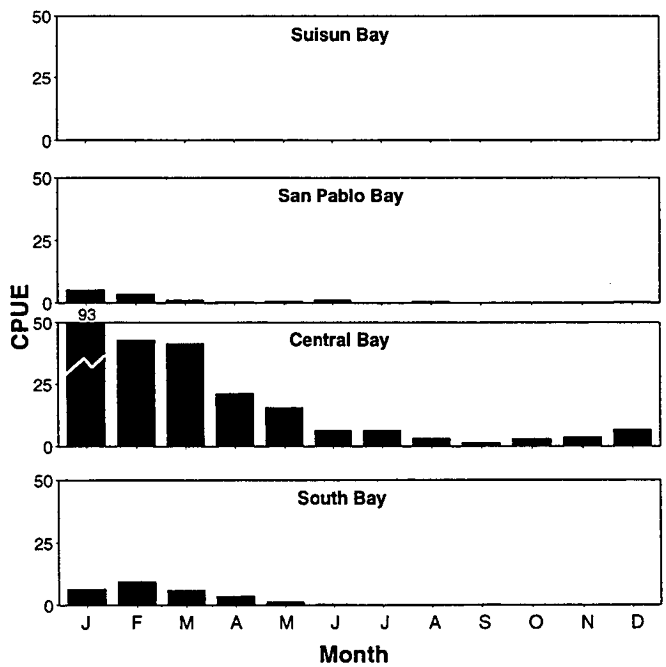

Figure 29 Seasonal distribution of age–1+ English sole collected with the otter trawl. Data are mean CPUE by month and region from 1981 to 1988.

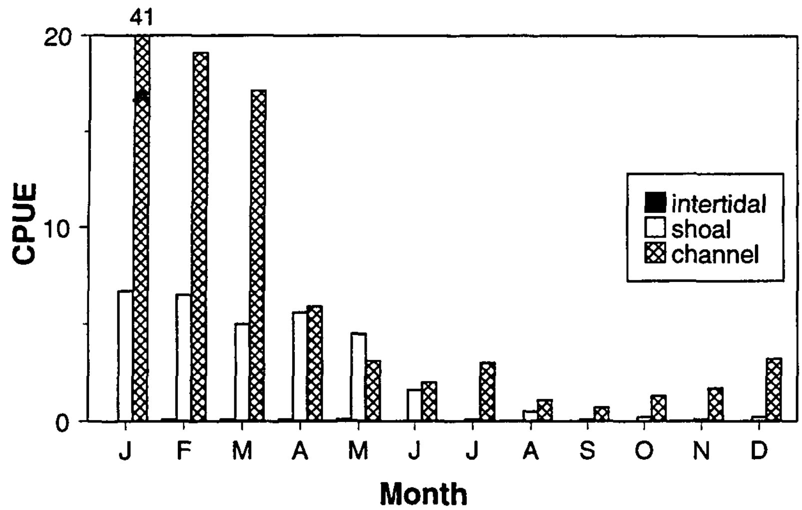

Figure 30 Depth distribution of age–1+ English sole collected with the beach seine (intertidal) and the otter trawl (shoal and channel). Data are mean CPUE by month from 1981 to 1986 (beach seine) and from 1981 to 1988 (otter trawl).

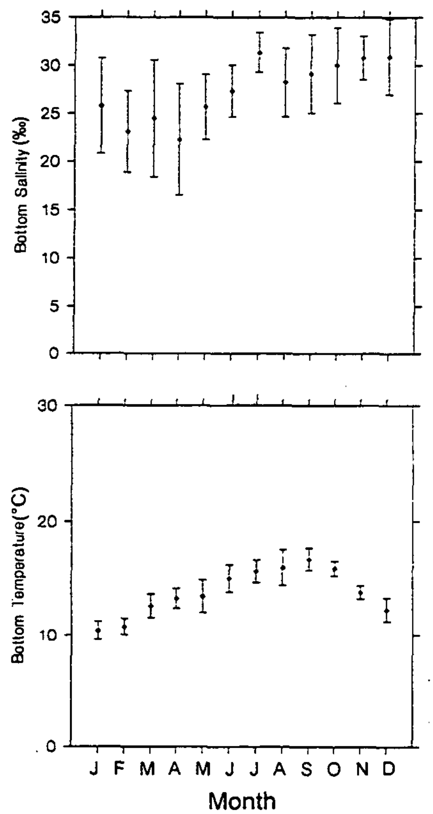

Figure 31 Salinity (‰) and temperature (°C) distributions of age–1+ English sole collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

Discussion

English sole used the San Francisco Estuary as a nursery area, immigrating primarily as settled age–0 fish, remaining for 6 to 18 months, then emigrating to the coast to mature and complete their life cycle (see Figure 19). During this estuarine nursery period, they underwent ontogenetic changes in their depth, temperature, and salinity distributions. These patterns of estuarine use were very similar to those described for other locations from Elkhorn Slough, California to British Columbia (Ketchen 1956, Olson and Pratt 1973, Pearcy and Myers 1974, Misitano 1976, Toole 1980, Bayer 1981, Bottom and others 1984, Krygier and Pearcy 1986, Rogers and others 1988, Gunderson and others 1990, Yoklavich and others 1991). On the Oregon coast, a majority of the age–0 population appears to rear in bays and estuaries (Olson and Pratt 1973, Krygier and Pearcy 1986, Rogers and others 1988). The large number of English sole collected here compared to other flatfish suggests that this is also true in California (see Table 1), in which case the large size of the San Francisco Estuary would make it an important nursery area for local stocks. However, little is known about coastal rearing. Limited otter trawl sampling in the Gulf of the Farallones (2 tows at 7 stations in February, June and October, 1984 to 1988; City of San Francisco Outfall Monitoring Program, unpublished data) caught age–0 fish in each month, but most were caught in October as would be the case if estuary-reared fish emigrated in fall. Thus, as in Yaquina Bay, the estuary appears to be an important but not an exclusive nursery area. Another way to evaluate the importance of estuarine rearing would be to compare estuarine abundance with the commercial catch 3 to 5 years later.

The ontogenetic shifts in the depth, salinity and temperature distributions of English sole in the San Francisco Estuary have also been seen in other bays and estuaries (Toole 1980, Bottom and others 1984, Krygier and Pearcy 1986, Yoklavich and others 1991). The geographic distribution of English sole in the estuary appeared to be related to salinity and temperature. Age–0 fish initially migrated to intertidal and subtidal areas where, in March, most of the population was in 12‰ to 24‰ salinity and 12.8 to 14.5 °C. In most years these conditions were found in San Pablo Bay, but in low outflow years, particularly 1987 to 1992, they extended into Suisun Bay (see Figure 24). Conversely, during extremely high outflow years such as 1983 or when high outflow occurred during early spring, as in 1986, salinity <12‰ eliminated or reduced use of San Pablo and Suisun bays. Later in spring as salinity increased, temperatures appeared to limit use of these bays. Laboratory experiments determined an LL_{50} of 26.1 °C for age–1+ fish (Ames and others 1978). In the estuary, fish left intertidal habitats at high temperatures. As intertidal temperatures approached and passed 20 °C in May and June, age–0 fish began to move to deeper and cooler shoal and then channel areas and toward Central Bay (see Figure 27). As this movement continued through the summer, it effectively stabilized the temperature distribution of age–0 fish (see Figure 28). In Elkhorn Slough, English sole were not collected from intertidal areas (Yoklavich and others 1991). Yoklavich (1991), referring to an earlier paper, suggests that thermal tolerance limited shallow water use in Elkhorn Slough and similar areas at the southern edge of their range.

Their depth, salinity and temperature ranges initially separated age–0 English sole from similar-sized speckled sanddabs which did not inhabit intertidal areas and tended to be more evenly distributed across channel and shoals, and from starry flounder which were found in fresher and warmer waters.

Starry Flounder

Introduction

The starry flounder, *Platichthys stellatus,* ranges from Santa Barbara, California northward to Arctic Alaska, then southwest to the Sea of Japan (Miller and Lea 1972). It is found from <1 m to about 275 m (Miller and Lea 1972). Juveniles seek shallow, fresh to brackish water in bays and estuaries to rear, but adults primarily inhabit coastal marine water (Orcutt 1950, Haertel and Osterberg 1967, Bottom and others 1984, Hieb and Baxter 1993). Though seldom targeted, the starry flounder is common in both commercial and recreational fisheries of northern and central California (Orcutt 1950, Haugen 1992, Karpov and others 1995).

In Monterey Bay, spawning occurs between November and February (Orcutt 1950) in shallow, coastal marine areas near river and slough mouths (Orcutt 1950, Garrison and Miller 1982, Wang 1986). Some spawning may occur within San Francisco Bay (Radtke 1966, Moyle 1976). However, no ripe female starry flounder were collected in San Francisco Bay during winter surveys in the mid-1980s (B. Spies, personal communication, see "Notes"), nor were any mature flounder, eggs or prolarvae collected from the estuary between 1978 and 1982 (Wang 1986).

Starry flounder eggs and larvae are pelagic and are found mostly in the upper water column (Orcutt 1950, Wang 1986). Larvae are approximately 2 mm long at hatching and settle to the bottom about 2 months later at approximately 7 mm SL (Policansky and Sieswerda 1979, Policansky 1982). They depend upon favorable ocean currents to keep them near their estuarine nursery areas prior to settlement. Transforming larvae and the smallest juveniles migrate from the coast to brackish or freshwater where they rear for 1 or more years (Haertel and Osterberg 1967, Bottom and others 1984, Wang 1986, Hieb and Baxter 1993).

As they grow, juveniles move to higher salinity, but appear to remain within estuaries through at least their 2nd year (Haertel and Osterberg 1967, Bottom and others 1984, Hieb and Baxter 1993). Most males mature by the end of their 2nd year of life and 220 to 276 mm SL, whereas, females mature at age 3 or 4 and 239 to 405 mm SL (Orcutt 1950). During the late fall and winter, mature starry flounder probably migrate to shallow coastal waters to spawn (Orcutt 1950). They reach a maximum length of 915 mm (Miller and Lea 1972).

Methods

Fish were grouped by length into several developmental and age categories. In the plankton net, 1 to 4 mm and 6 to 12 mm TL larvae were classified as recently hatched and pre-settlement larvae, respectively (Policansky and Sieswerda 1979, Policansky 1982). In the beach seine and otter trawl, fish in the 10 to 29 mm size range were classified as recently settled; settlement occurs at about 10 mm (Policansky and Sieswerda 1979, Policansky 1982). Visual inspection of length frequency data (mm TL) was used to determine cutoff lengths to separate age–0 fish from age–1+ (all older age classes). Fish $\geq$ 410 mm were classified as mature (Orcutt 1950).

A January 1 birth date was assigned to all larvae and age–0 fish. Larval abundance and distribution were based on total catch, without correction for effort or for incomplete sampling in 1980 and 1989. Monthly cutoff lengths used to separate age–0 and age–1+ fish were 60, 60, 70, 80, 95, 110, 125, 140, 150, 155, 160, and 165 mm TL for January through December. Annual abundance indices for age–0 and age–1+ fish were the means of May to October and February to October monthly indices from the otter trawl. No correction was made for the lack of data for August to October 1989 or August 1995. All distribution analyses were based upon monthly mean CPUE for 1981 to 1988.

Results

Length Analyses

Larval starry flounder captured by the plankton net ranged from 1.7 to 11.3 mm and age–0 fish ranged from 34.5 to 53 mm. Recently hatched larvae were collected throughout the year, but pre-settlement larvae were only collected from March to June (Table 12). Starry flounder collected by the beach seine ranged from 17 to 475 mm; those collected by the otter trawl were 19 to 638 mm. Beach seine and otter trawl capture of recently settled fish occurred during 2 periods: December to February and May to July (Figure 32). There was very little evidence of growth and recruitment of fish that settled during the winter period, but those caught in the spring-summer period followed the collection of pre-settlement larvae (see Table 12) and preceded collection of larger individuals, evidence of further growth and recruitment (see Figure 32).

There was a clear distinction between the lengths of age–0 and age–1+ starry flounder from April to July, and only a slight overlap for the rest of the year (see Figure 32). Growth of age–0 fish was rapid through summer and early fall, reaching 70 to 90 mm by August. Growth slowed considerably between September and December when the modal size range increased to only 90 to 110 mm. Nonetheless, by December, some age–0 fish reached 150 mm. Age–1 and age–2 fish were not easily separable using length data, but length frequency modes indicated that both age groups were present in the estuary (see Figure 32). Older age groups were also present but length modes were not apparent. Mature-sized (≥410 mm) fish were collected in the estuary primarily from May to October (see Figure 32).

Abundance and Distribution of Larvae

Annual larval catch reached a peak of 59 in 1980, declined precipitously in 1981, rose sharply in 1982, and then, after a moderate downturn in 1983 and 1984, returned to intermediate levels from 1985 through 1988 (Tables 13 and 14). Annual catch reached a minimum of 2 in 1989, when sampling took place only from January through May (see Table 13). Larvae were collected throughout the estuary, but over half came from Central Bay (see Table 13). Greater numbers of larvae were caught in San Pablo than in South Bay. Catches from San Pablo Bay, Suisun Bay, and the west delta increased between 1984 and 1988.

Table 12 Length frequency (mm TL) of larval starry flounder captured in the plankton net from 1980 to 1989

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1.0 - 1.9				1				3					4
2.0 - 2.9	2	1	1	7	2	3	21	14	31	15	15	7	119
3.0 - 3.9		9	4	10	2			1	1		2	1	30
4.0 - 4.9		2	1	3							1		7
5.0 - 5.9													
6.0 - 6.9					9								9
7.0 - 7.9			1	4	24								29
8.0 - 8.9			1	8	37	1							47
9.0 - 9.9				2	3								5
10.0 - 10.9													
11.0 - 11.9			1										1
Total	2	12	9	35	77	4	21	18	32	15	18	9	251

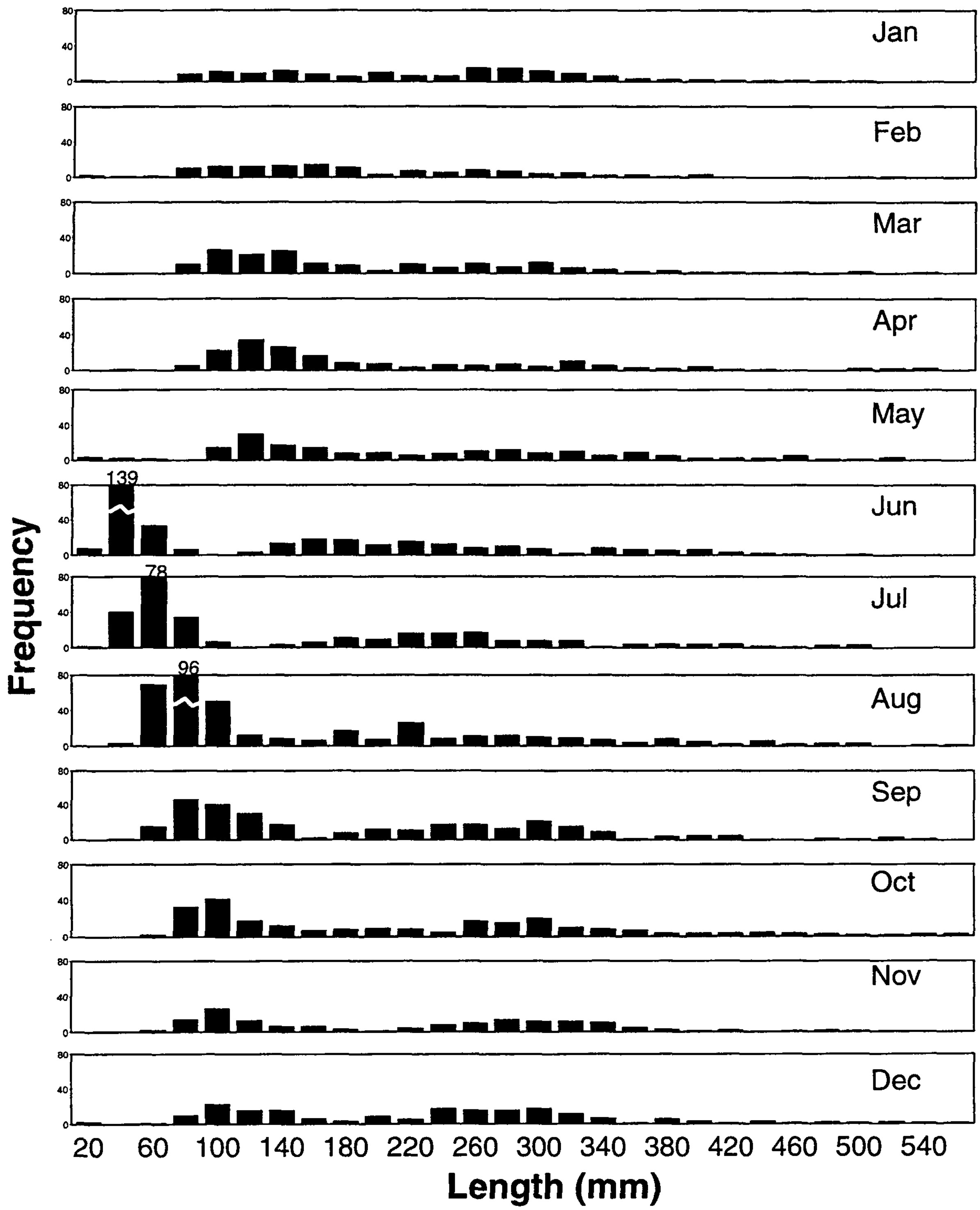

Figure 32 Length frequency (mm TL) by month of starry flounder collected with the beach seine and otter trawl from 1981 to 1988. Fish <30 mm were considered recently settled and those ≥410 mm were considered mature.

Table 13 Annual abundance (right column) and distribution of starry flounder larvae collected in the plankton net from 1980 to 1989. Data are annual catches by region with no correction for partial-year sampling in 1980 and 1989.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*	*Total*
1980	5	41	13	0	0	59
1981	1	7	0	0	0	8
1982	4	22	8	0	0	34
1983	1	11	2	0	0	14
1984	0	3	6	4	0	13
1985	1	18	12	2	1	34
1986	2	14	20	2	0	38
1987	4	12	7	3	0	26
1988	1	10	10	2	0	23
1989	0	2	0	0	0	2
Total	19	140	78	13	1	251

Table 14 Monthly abundance larval starry flounder captured in the plankton net from 1980 to 1989. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	0	3514	53120	0	0	1074	754	969	3666	0	5736
1981	0	0	0	1433	1433	0	0	1433	2507	0	1469	0	752
1982	0	11497	0	5197	2938	0	0	565	1039	1578	0	6509	2666
1983	0	0	2507	3976	3188	0	0	0	0	358	431	1074	1049
1984	1074	0	0	0	4147	0	0	323	431	0	0	0	446
1985	0	1433	1828	1349	0	0	19024	1074	1433	0	2367	0	2592
1986	2015	0	0	0	6317	1074	0	2938	9719	2402	6088	0	2594
1987	0	0	0	3806	4856	1433	0	4909	4370	3942	990	646	2268
1988	0	0	538	4355	0	1397	716	4728	1613	1828	1074	0	1477
1989	0	0	1791	0	0								
1981–1988	386	1616	609	2515	2860	488	2468	1996	2639	1264	1552	1029	

Abundance and Distribution of Age–0 and Older Fish

Annual Abundance

The abundance of age–0 starry flounder was at a maximum in 1980, declined precipitously in 1981, rose sharply in 1982, and then declined to and remained at low levels from 1987 to 1994, reaching zero in 1992 (Figure 33, Table 15). After 1986, only 1995 was a good year for age–0 abundance. Age–1+ fish abundance rose to a peak of 6,954 in 1983, then declined to and remained at low levels from 1988 through 1995 (see Figure 33, Table 16). Age–1+ fish abundance reached a minimum of 100 in 1993.

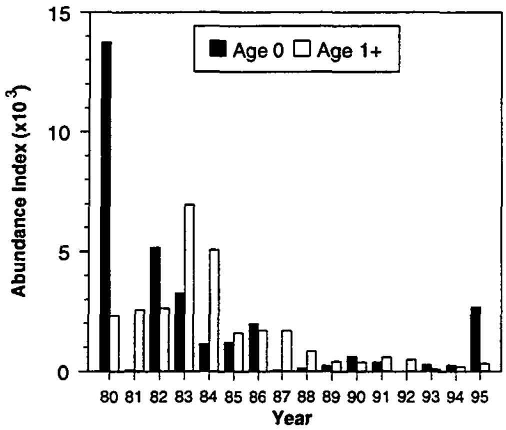

Figure 33 Annual abundance of age–0 and age–1+ starry flounder collected with the otter trawl from 1980 to 1995. Data are mean May to October (age 0) and February to October (age 1+) abundance indices.

Table 15 Monthly abundance age-0 starry flounder captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Oct*
1980		0	0	0	0	4515	12809	32572	16370	16227	4673	1173	13749
1981	0	0	0	55	71	69	116	0	134	0	65	55	65
1982	0	497	0	0	65	4701	5943	7717	5767	6868	4351	2414	5177
1983	0	134	0	0	256	2278	4374	6994	1306	4353	1928	2627	3260
1984	0	0	0	0	0	2284	1426	1221	1175	666	0	269	1129
1985	0	0	0	0	0	687	55	2243	3827	409	228	202	1204
1986	0	0	0	0	0	381	2159	8656	629	62	0	522	1981
1987	0	0	0	0	0	84	0	69	195	0	0	0	58
1988	0	0	0	0	0	335	145	0	346	0	103	65	138
1989	0	0	0	0	0	55	328	589					243
1990		0	0	0	84	881	479	1537	678	62			620
1991		0	0	0	0	343	1110	311	511	0			379
1992		0	0	0	0	0	0	0	0	0			0
1993		0	0	0	0	117	553	445	483	0			266
1994		0	0	0	0	0	560	574	416	0			258
1995	0	0	0	0	0	1277	8962		2031	1135	317	343	2681
1981–1988	0	79	0	7	49	1352	1777	3363	1672	1545	834	769	

Table 16 Monthly abundance age–1+ starry flounder captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		3133	1571	1846	3540	848	3671	1591	461	4267	1409	666	2325
1981	2082	3040	3120	3834	1705	818	2447	4656	1905	1402	1822	2997	2547
1982	2992	422	959	1632	3766	5087	1778	2907	2355	4627	5393	901	2615
1983	3584	2068	3993	6831	11117	7916	6265	9117	7028	8255	3375	5724	6954
1984	4871	2569	9998	4728	5901	4132	6999	4941	3727	2523	797	2299	5058
1985	523	1939	1320	556	1414	761	1514	2812	2976	971	563	626	1585
1986	624	993	961	810	2389	470	2970	1716	2022	2951	1515	706	1698
1987	1011	1457	666	1049	791	3821	1375	2098	1419	2422	2232	2898	1678
1988	1395	260	1297	1631	1131	521	333	514	1833	0	1146	69	836
1989	292	180	433	857	625	0	300	459					408
1990		0	0	438	1172	473	329	281	188	541			380
1991		55	647	250	97	576	920	767	910	1089			590
1992		207	1441	814	384	0	0	549	567	461			491
1993		173	0	0	173	0	331	0	0	219			100
1994		55	0	0	75	651	0	705	243	0			192
1995	138	48	0	669	192	173	269		1203	0	1102	959	319
1981–1988	2135	1594	2789	2634	3527	2941	2960	3595	2908	2894	2105	2028	

Seasonal Abundance

The initial weak recruitment of age–0 starry flounder to the estuary from January to May was followed by a steady increase in abundance from June to August, then by a decline to December (Figure 34, see Table 15). In January, age–1+ abundance was high relative to that of age–0 fish in December (see Figure 34, see Table 16). After a small decline in February, age–1+ abundance increased to an initial mode in May followed by a second mode in August, then declined slowly to December (see Figure 34). The monthly abundance of age–1+ fish was consistently higher than that of age–0 fish, in part, because the age–1+ group contained several age classes. The low abundance period for age–1+ fish, November to February, coincided with a reduction in the number of mature-sized fish caught in the estuary (compare to Figure 32).

Annual Distribution

Age–0 starry flounder were captured throughout the estuary, but annual CPUE was always highest upstream of Central Bay (Figure 35). Age–0 fish were rarely caught in Central Bay or South Bay, and when they were it was usually during a high outflow year (that is, 1980, 1982, 1983, 1984, 1986, 1993, and 1995). Maximum CPUE was in Suisun Bay or the west delta during low outflow years (1981, 1985, 1987–1992, 1994) and in San Pablo Bay during most high outflow years. Although outflow was high during the winter of 1984, flows diminished to low flow conditions by May and June when age–0 fish entered the estuary, resulting in a distribution typical of low outflow conditions.

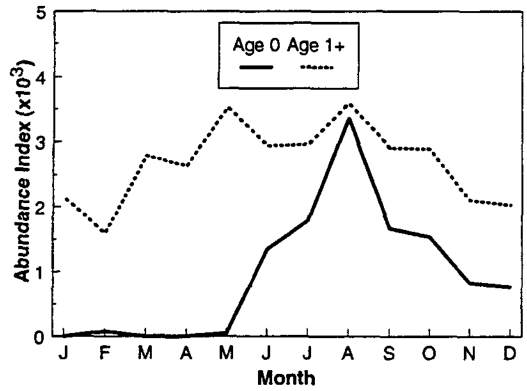

Figure 34 Seasonal abundance of age–0 and age–1+ starry flounder collected with the otter trawl. Data are mean monthly abundance indices from 1981 to 1988.

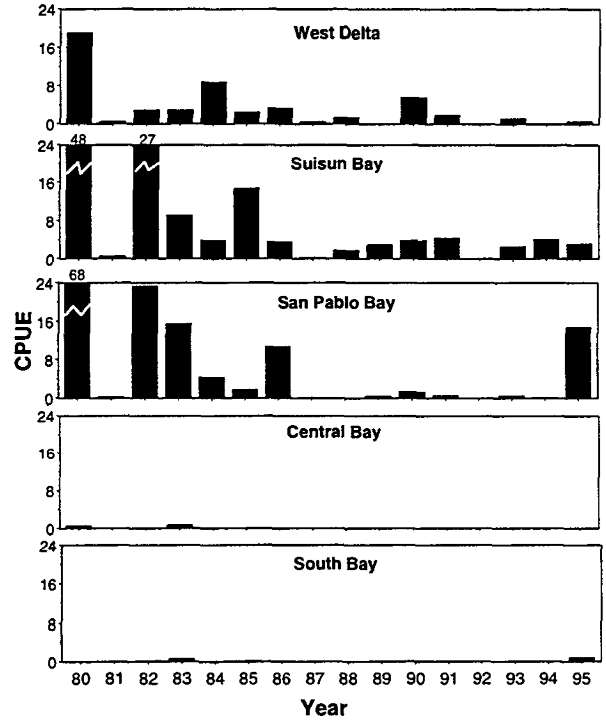

Figure 35 Annual distribution of age–0 starry flounder collected with the otter trawl from 1980 to 1995. Data are mean May to October CPUE by region.

Age–1+ starry flounder were also captured throughout the estuary, but were centered in San Pablo Bay (Figure 36). Unlike age–0, age–1+ fish were common in Central and South bays, and were relatively rare in the west delta. The distribution of age–1+ fish did not change with outflow.

Seasonal Distribution

Catches of age–0 starry flounder were low before June. In May and June, age–0 fish were found primarily in Suisun Bay and the west delta (Figure 37). By July, few age–0 fish were captured in the west delta, but catches were relatively high in Suisun and San Pablo bays, and remained relatively high through December. In December, CPUE again increased in the west delta.

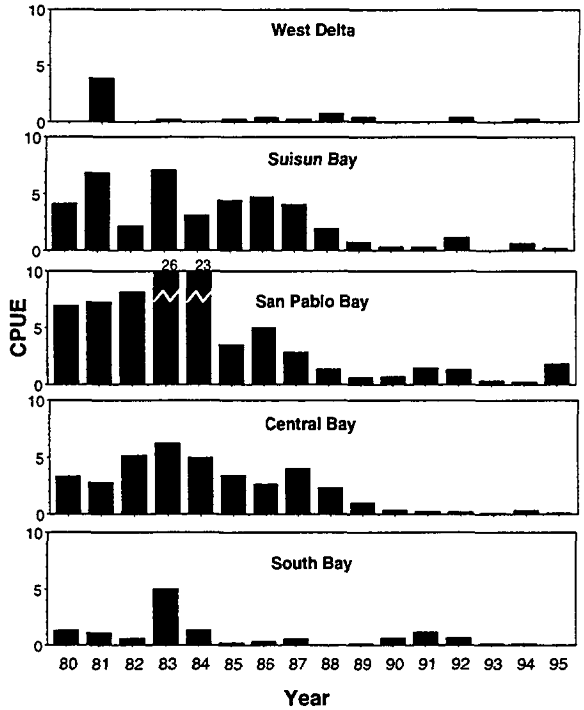

Figure 36 Annual distribution of age–1+ starry flounder collected with the otter trawl for 1980 to 1995. Data are mean February to October CPUE by region.

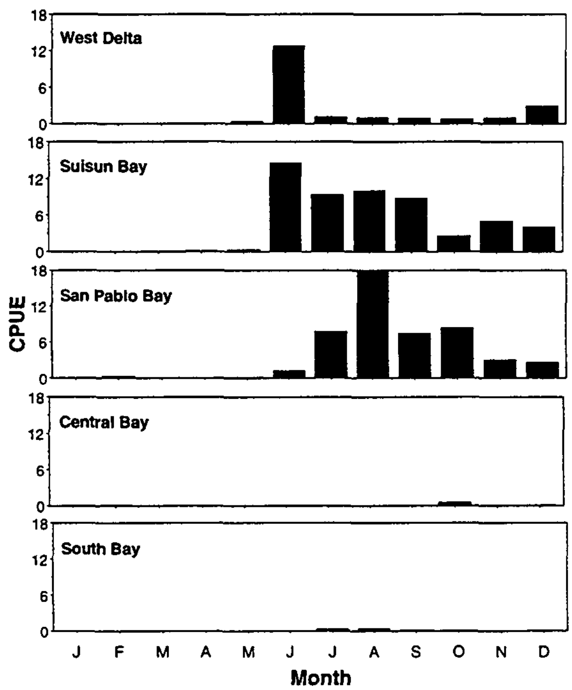

Figure 37 Seasonal distribution of age–0 starry flounder collected with the otter trawl. Data are mean CPUE by month and region from 1981 to 1988.

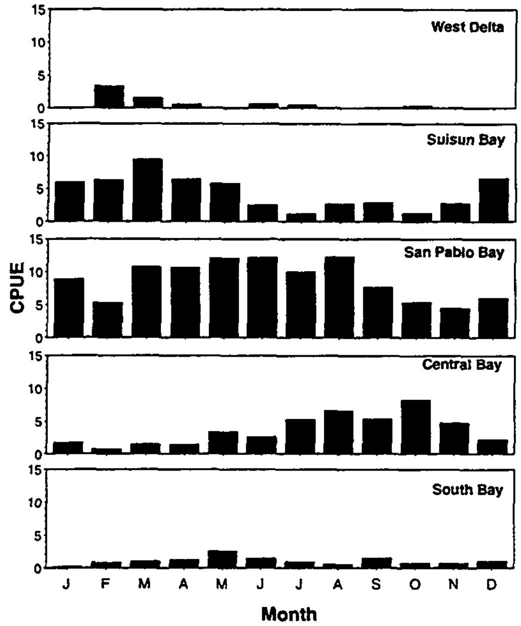

Figure 38 Seasonal distribution of age–1+ starry flounder collected with the otter trawl. Data are mean CPUE by month and region for 1981 to 1988.

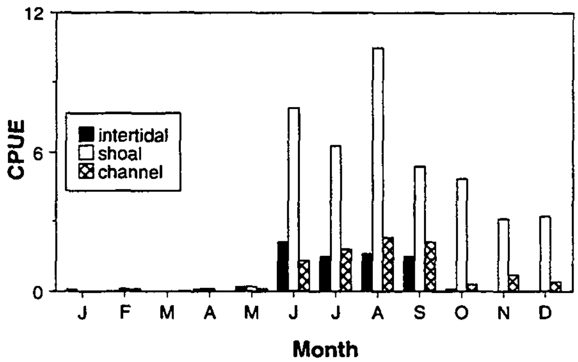

Figure 39 Depth distribution of age–0 starry flounder collected with the beach seine (intertidal) and the otter trawl (shoal and channel). Data are mean CPUE by month for 1981 to 1986 (beach seine) and for 1981 to 1988 (otter trawl).

In January, age–1+ starry flounder were distributed primarily in Suisun and San Pablo bays (Figure 38). Use of the west delta was highest in February and March. A February through May decline in CPUE in the west delta coincided with the start of a general downstream movement toward San Pablo and Central bays that continued into the fall (see Figure 38). After March, few age–1+ fish were captured in the west delta. Use of South Bay occurred primarily from March to June. By July and continuing through November, most age–1+ fish were caught in Central and San Pablo bays. In December, their range shifted back upstream slightly (see Figure 38).

Age–0 starry flounder were collected in higher numbers over shoals than in channels or in the intertidal zone throughout the year (Figure 39). Catches of age–0 fish were low in all areas from January to April and began to rise in May. They were highest over shoals during the period of maximum abundance from June to September and a little higher in the channels than in intertidal areas during these months.

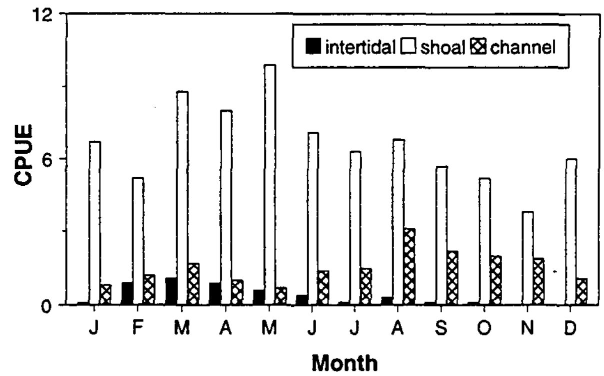

Figure 40 Depth distribution of age–1+ starry flounder collected with the beach seine (intertidal) and the otter trawl (shoal and channel). Data are mean CPUE by month for 1981 to 1986 (beach seine) and for 1981 to 1988 (otter trawl).

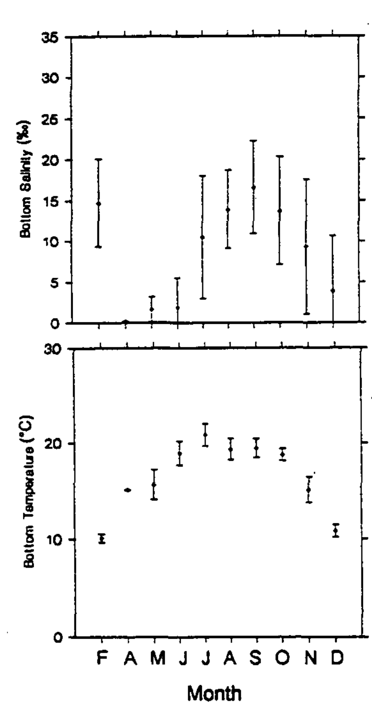

Figure 41 Salinity (‰) and temperature (°C) distributions of age–0 starry flounder collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

Age–1+ starry flounder were always most abundant over shoals and always least abundant in the intertidal (Figure 40). Shoal abundance peaked from March to May, intertidal abundance from February to June, and channel abundance from August to October.

Salinity and Temperature

Age–0 starry flounder tended to seek warm, low salinity areas to rear, and though as a group they shifted into higher salinity water during late summer and fall, part of the population remained in freshwater all year (Figure 41). In February, a few age–0 fish were captured from 9.1‰ to 22.1‰, but from April to June monthly salinity means were all <2‰, and the maximum salinity was only 12.2‰. From June to September, age–0 fish were found in progressively higher salinities (see Figure 41) as a result of their downstream movement (see Figure 37). From September to December, age–0 fish faced progressively lower salinity water as a result of a slight upstream movement (see Figure 37) and increased outflows in the fall of 1982 and 1983, when abundance was high. In June, age–0 fish were found in temperatures ranging from 16.4 to 22.6 °C (mean about 19 °C, see Figure 41). Except for a few found as high as 23.8 °C in July, most remained within this 16.4 to 22.6 °C temperature range from June through October. After October, they inhabited progressively cooler water through the end of the year.

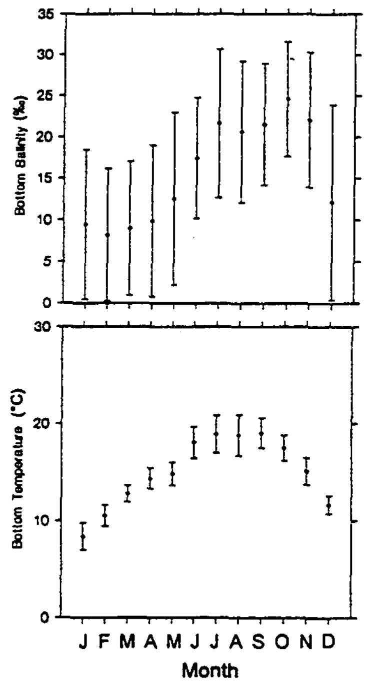

Figure 42 Salinity (‰) and temperature (°C) distributions of age–1+ starry flounder collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

Age–1+ starry flounder had broad monthly salinity and temperature ranges, reflecting their extensive geographical distribution (Figure 42). From January through April, age–1+ fish faced mean salinities from 8‰ to 10‰, and monthly ranges of 0.1‰ to >15‰. From May through July, age–1+ fish moved into more saline waters (see Figure 42). Age–1 salinity ranges stabilized somewhat from July to November, except for an upward shift in October; means ranged from 20.6‰ to 22.1‰ (24.6‰ in October). Although monthly salinity ranges were broad for August to October, age–1+ fish were no longer collected from freshwater: salinity minima ranged from 3.7‰ to 6.9‰. In December, the age–1+ fish that remained in the estuary were found in lower salinity water.

Discussion

Although all life stages of starry flounder, except eggs, were captured in the estuary, it was primarily used as a nursery area for fish age 2 and younger. The magnitude and range of use were probably underestimated because starry flounder inhabit areas not sampled by the study, for example, the Napa Marsh (California Department of Fish and Game (CDFG), unpublished data), the Suisun Marsh (Moyle and others 1986), and the central, eastern, and southern delta (Radtke 1966, CDFG unpublished data). Historically, starry flounder may have spawned in the estuary (Radtke 1966, Moyle 1976), but few larvae were collected by this study and by Wang (1986) and no ripe adults were captured (B. Spies, personal communication, see "Notes"). Low larval catches were also recorded for other estuaries used by juvenile starry flounder. In the Columbia Estuary, no larvae were taken during a year of monthly plankton sampling at 7 locations (Misitano 1977), even though the upper estuary was an important nursery for juveniles (Haertel and Osterberg 1967). During 11 years of sampling Yaquina Bay, another important nursery area (Bayer 1981), only 3 larvae were collected (Pearcy and Myers 1974). On the other hand, starry flounder larvae were common in nearshore coastal waters off Oregon (Richardson and Pearcy 1977). Thus, most spawning probably takes place in the coastal marine environment, and transforming larvae and small juveniles seek out estuaries for rearing.

Although there was evidence of some immigration by pre-settlement (that is, transforming) larvae, most starry flounder immigrated as settled, 30 to 70 mm juveniles (Radtke 1966, this study). Otter trawl and beach seine sampling during April and May failed to collect sufficient numbers of 10 to 29 mm age–0 fish to account for the large numbers of 30 to 69 mm of fish caught in June and July (see Figure 32). Sudden estuarine entry of ≥30 mm fish in late May or June is common in Elkhorn Slough, California (Yoklavich and others 1991), and in the Columbia River Estuary (Haertel and Osterberg 1967, McCabe and others 1983, Bottom and others 1984). However, in the Salinas River, California, Orcutt (1950) collected numerous 10 to 29 mm fish from March through May.

Immigration of age–0 fish may be triggered by rising estuarine temperature. Typically, by March estuarine temperatures surpass those of the nearshore coastal areas (see Salinity and Temperature chapter, Figure 12). In April, the difference becomes more pronounced as coastal temperatures decline with the start of upwelling and estuarine temperatures continue to seasonally warm. Thus, temperature and salinity may act as cues to guide juveniles to the estuary.

The importance of estuarine rearing for starry flounder may be inferred from age–0 habitat that was predominantly fresh to mesohaline during their 1st year (see Figure 41), and from the relative lack of age–0, age–1 and age–2 fish in coastal marine areas (City of San Francisco Bureau of Water Pollution Control, unpublished data 1987 to 1990; Rogers and others 1988; Yoklavich and others 1991). In previous analyses, specific habitat criteria were established for starry flounder <70 mm in the San Francisco Estuary: 90% were collected from habitat having bottom depth <7 m, and salinity <22‰ (Hieb and Baxter 1993). These criteria defined "critical" habitat for recently immigrating fish and habitat for age–1 fish remained very similar (Hieb and Baxter 1993). Based on these criteria, habitat area in the estuary was significantly and positively related to March through June freshwater outflow ($r^2 = 0.917$, $P < 0.001$, df = 9). Abundance in the estuary was also significantly related to outflow during the same period ($r^2 = 0.646$, $P < 0.\ 01$, df = 9). In the Columbia River Estuary, age–0 and age–1 starry flounder are found in similar low salinity, and intertidal and subtidal habitats (McCabe and others 1983, Bottom and others 1984). Though age–0 starry flounder were common in the estuary, they were rarely collected in the Gulf of the Farallones (B. Sak, personal communication, see "Notes"). This pattern of estuarine rearing with little or no evidence of marine rearing is found elsewhere in their range (Rogers and others 1988, Yoklavich and others 1991). The exclusiveness of their fresh and brackish water rearing habitat and the relationship between freshwater outflow and their abundance is strong evidence for estuarine dependence (Emmett and others 1991, Hieb and Baxter 1993, this study). However, coastal spawning and the wide variation in abundance during high outflow years suggest that ocean conditions and outflow in combination affect year class strength (Hieb and Baxter 1993).

Age–0 starry flounder inhabit lower salinity and warmer water than other flatfish species in the estuary and hence, face little competition during their first few months of settled life. These same conditions lead to rapid growth, which in turn can reduce the period of extreme vulnerability to predation.

Diamond Turbot

Introduction

The diamond turbot, *Hypsopsetta guttulata,* ranges from Magdalena Bay, Baja California, northward to Cape Mendocino, California. There is also an isolated population in the Gulf of California (Miller and Lea 1972). The diamond turbot is captured by both commercial and recreational fishers, but not in sufficient numbers to be important to either group (Leos 1992a). It ranges in depth from 1 to 50 m.

Spawning occurs from September through late February but peaks between November and January (Lane 1975, Wang 1986). Most spawning takes place within 2 km of shore (Barnett and others 1984), and often within or just off the mouths of bays and estuaries (Eldridge 1975, Lane 1975, Kramer 1990a, Kramer 1991b). Transforming larvae (4.4 to ≤8.8 mm SL, Ahlstrom and others 1984) appear to seek out bays, sloughs, and estuaries as nursery areas (Lane 1975, Kramer 1990a, Kramer 1991b). Recently settled juveniles (≤14 mm SL) concentrate mainly in shallow, backbay areas and there is a positive relationship between depth of capture and length (Kramer 1990a, Kramer 1991b). Diamond turbots live nearshore throughout their lives. Females mature in 2 to 3 years at about 180 mm TL (Lane 1975). Diamond turbots reach a maximum size of about 450 mm TL (Miller and Lea 1972).

Methods

Plankton net, beach seine, and otter trawl length data were used in length frequency analyses. Juveniles <17 mm TL were considered recently settled. A single cutoff length of 120 mm TL was used to separate juveniles from adults in all months.

The annual abundance of larvae was calculated as mean April to December monthly abundance. Monthly abundance indices were averaged for 1980 to 1988 to show seasonal abundance. Annual distribution was based upon the mean April to December CPUE by region. A January 1 hatch date was assumed for all juvenile fish. Annual abundance of juveniles was based upon total catch in the beach seine, whereas adult annual abundance was calculated as the mean of February to October monthly abundance indices from the otter trawl. No corrections were made for missing months in 1989 or 1995.

Results

Length Analyses

Diamond turbot larvae collected with the plankton net ranged from 1.5 to 11.5 mm TL. No juvenile fish were caught with this net, although the 11.5 mm individual was almost a juvenile. Diamond turbot collected with the otter trawl ranged from 23 to 454 mm and those in the beach seine ranged from 30 to 329 mm. Thus, no recently settled fish were captured with either the beach seine or the otter trawl. Between 1981 and 1988, all fish <120 mm were collected with the beach seine and all larger fish except 2 were collected with the otter trawl (Figure 43). No pattern of growth was apparent from length frequency of the few juveniles collected. There was a broad band of sizes (about 120 to 180 mm) not collected with either gear type. Most fish collected with the otter trawl were >180 mm and were adults (Lane 1975).

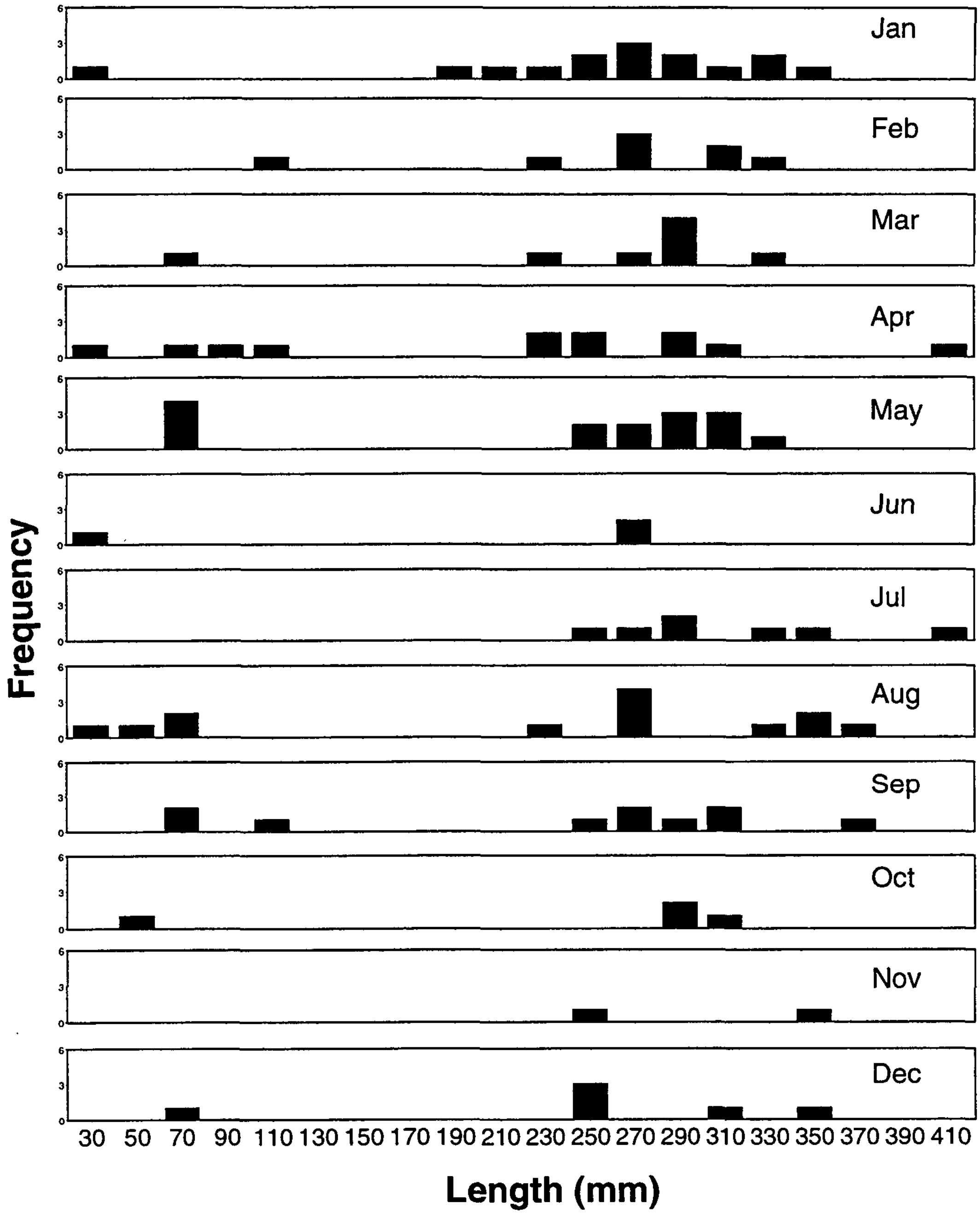

Figure 43 Length frequency (mm TL) by month of diamond turbot collected with the beach seine and otter trawl from 1981 to 1988. Fish <17 mm were considered recently settled and those ≥180 mm were considered mature.

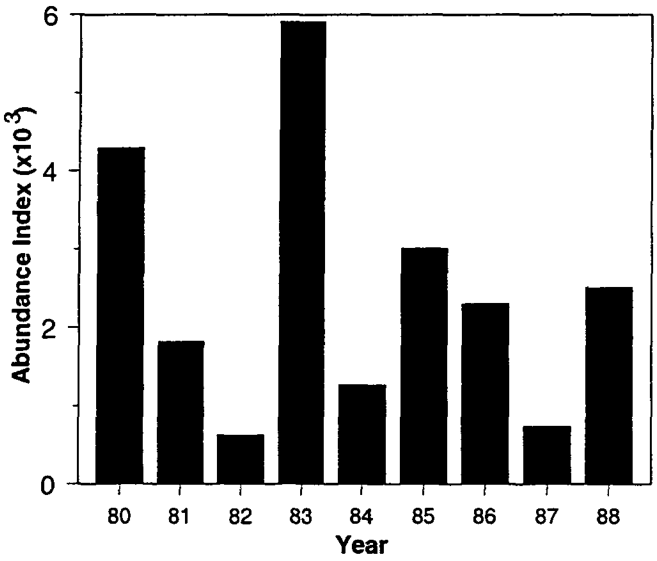

Figure 44 Annual abundance of larval diamond turbot collected with the plankton net from 1980 to 1988. *Data are mean April to December abundance indices.*

Table 17 Monthly abundance of larval diamond turbot captured in the plankton net from 1980 to 1989. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1980 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Apr–Dec*
1980		0	0	0	0	0	860	3369	2582	861	16807	14155	4293
1981	0	0	0	3871	2893	3995	574	1245	1749	1147	0	941	1824
1982	0	0	0	0	0	0	0	0	565	716	4338	0	624
1983	0	0	0	0	0	0	1791	0	14465	19211	17729	0	5911
1984	0	0	0	0	0	0	2221	3610	3368	431	1791	0	1269
1985	0	0	0	0	0	2823	4877	3290	565	4090	11478	0	3014
1986	0	0	0	0	0	0	1317	1756	13149	1505	2258	753	2304
1987	0	0	0	0	0	1505	538	1292	538	1938	861	0	741
1988	0	0	0	0	0	0	0	431	15831	3715	2646	0	2514
1989	0	0	0	376	0								
1980–1988	0	0	0	484	362	1040	1415	1453	6279	4094	5138	212	

Abundance and Distribution of Larvae

Annual larval abundance oscillated widely without a trend from 1980 to 1988 (Figure 44, Table 17). Abundance was highest in 1983, lowest in 1982. Larvae were collected from April to December and abundance was highest from September to November (Figure 45, see Table 17). Larvae were caught from South Bay to Suisun Bay, but were rare in Suisun Bay (Table 18). Use of Suisun Bay occurred only during low outflow years with higher than average larval abundance, 1985 and 1988. Larval abundance was highest in South Bay in 5 of 9 years.

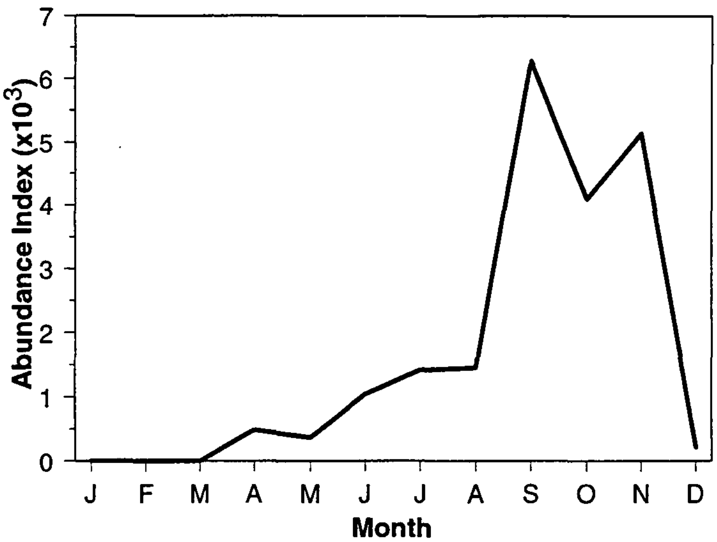

Figure 45 Seasonal abundance of larval diamond turbot collected with the plankton net. Data are mean monthly abundance indices for 1981 to 1988.

Table 18 Annual distribution of larval diamond turbot from the plankton net. Data are mean April to December CPUE by region. None were caught in the west delta.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*
1980	1.7	0.4	0.5	0
1981	0.6	0.1	0.7	0
1982	0.2	0.1	0	0
1983	0.7	1.6	0.3	0
1984	0.1	0.3	0.3	0
1985	1.2	0.2	0.5	0.5
1986	0.5	0.4	0.4	0
1987	0.1	0	0.7	0
1988	0.7	0.4	0.2	0.3
Mean	0.6	0.4	0.4	0.1

Abundance and Distribution of Juvenile and Adult Fish

Annual Abundance

Juvenile catch in the beach seine was zero in 1980 (Table 19). After an increase to a catch of 3 and a decline to 1 in 1981 and 1982, respectively, annual catch remained between 3 and 5 from 1983 through 1986. Adult abundance dropped sharply between 1980 and 1981, remained stable through 1985, then declined to a minimum of 132 in 1986 (Figure 46, Table 20). In 1987, adult abundance began a steady increase to a maximum of 812 in 1994, followed by a sharp decline in 1995.

Table 19 Annual abundance and distribution of juvenile diamond turbot from the beach seine. Data are total annual catch by region. None were collected in San Pablo Bay, Suisun Bay or the west delta.

Year	*South Bay*	*Central Bay*	*Total*
1980	0	0	0
1981	2	1	3
1982	0	1	1
1983	0	3	3
1984	2	1	3
1985	0	5	5
1986	2	2	4
Total	6	13	

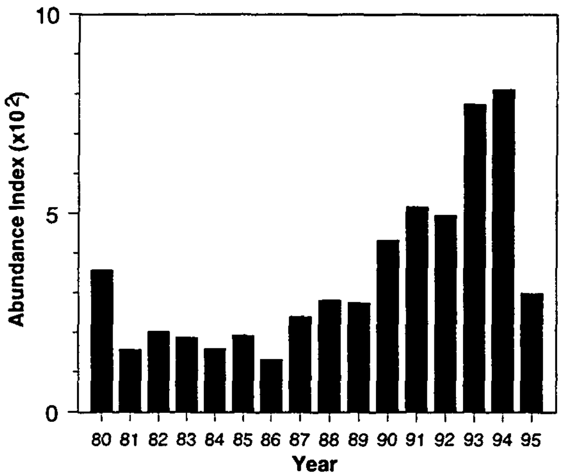

Figure 46 Annual abundance of adult diamond turbot collected with the otter trawl for 1980 to 1995. Data are mean February to October abundance indices.

Table 20 Monthly abundance of adult diamond turbot captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		2395	556	250	0	0	0	0	0	0	188	0	356
1981	701	288	250	0	250	0	344	278	0	0	0	0	157
1982	132	0	382	219	907	0	0	0	0	309	0	474	202
1983	156	134	0	344	0	0	250	965	0	0	270	0	188
1984	854	676	134	0	219	243	0	0	162	0	0	0	159
1985	281	0	0	435	0	0	188	706	162	243	0	0	193
1986	297	0	0	188	271	219	297	0	216	0	0	0	132
1987	115	344	216	0	0	0	541	189	683	189	211	622	240
1988	134	76	500	870	750	0	188	0	154	0	0	307	282
1989	0	0	563	0	0	297	1074	0					276
1990		915	817	0	115	345	281	250	737	439			433
1991		1229	1987	313	0	0	250	281	433	173			518
1992		1490	622	934	173	216	352	0	270	406			496
1993		1796	469	836	416	486	1035	1083	326	540			776
1994		1226	1419	935	0	1595	0	1097	819	216			812
1995	634	192	911	505	0	365	281		0	134	216	344	299
1981–1988	334	190	185	257	300	58	226	267	172	93	60	175	

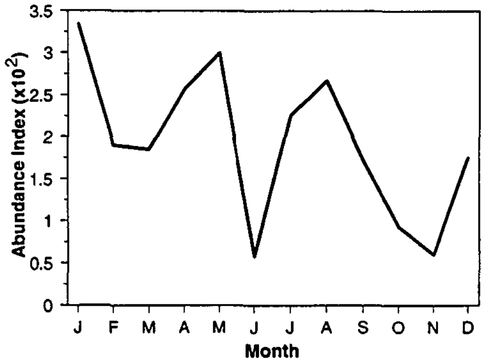

Figure 47 Seasonal abundance of adult diamond turbot collected with the otter trawl. Data are mean monthly abundance indices for 1981 to 1988.

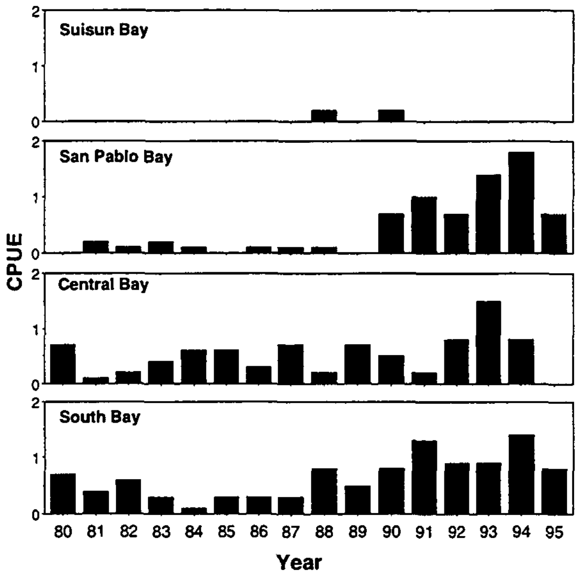

Figure 48 Annual distribution of adult diamond turbot collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region.

Seasonal Abundance

Juveniles were caught sporadically throughout the year, with slightly higher numbers caught in April, May, August, and September (see Figure 43). Adult abundance varied widely during the year. It was relatively high from December through May, declined sharply in June, increased sharply in July and remained high through September before declining and remaining relatively low in October and November (Figure 47, see Table 20).

Annual Distribution

Juveniles were collected only in Central and South bays (see Table 19). They were collected in Central Bay in every year except 1980 but were found in South Bay only in 1981, 1984 and 1986. Similar to larvae, adult diamond turbot were caught from South Bay to Suisun Bay (Figure 48). Captures from Suisun Bay only occurred during the drought years 1988 and 1990. Although some fish were caught in San Pablo Bay in most years, CPUE there was relatively low until the 1990s, when it was about as high or higher than the CPUE of other regions (see Figure 48).

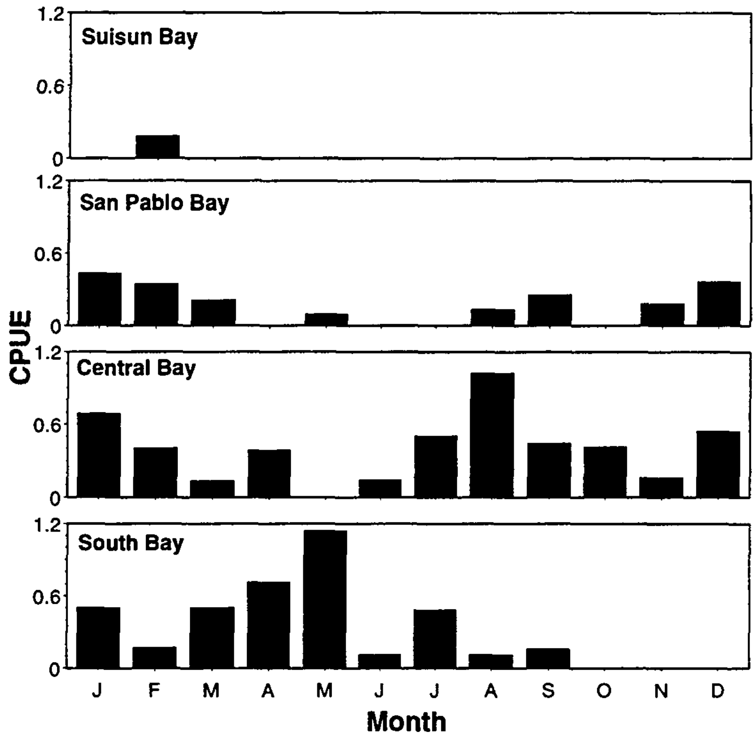

Figure 49 Seasonal distribution of adult diamond turbot collected with the otter trawl. Data are mean CPUE by month and region for 1981 to 1988.

Seasonal Distribution

Adult diamond turbot were generally distributed from South Bay to San Pablo Bay, though some were caught as far upstream as Suisun Bay in February of 1988 and 1990 (Figure 49). From spring to fall, they were only sporadically present in San Pablo Bay, but were consistently captured there from November to March. In Central Bay, adult CPUE was highest in August and lowest in May, the only month with 0 catch. Adults were present in South Bay only from January to September. Peak abundance in South Bay was in May when none were collected from Central Bay.

The depth distributions of juveniles and adults were assessed by comparing beach seine and otter trawl catches, and by comparing average monthly CPUE at channel and shoal stations. Of the 25 juvenile diamond turbot caught throughout the study period, 21 were caught in the beach seine and 4 in the otter trawl; 3 of 4 in the otter trawl came from shoal stations. Adults showed a preference for shallow water in winter.

Two adults were collected in the beach seine: 1 each in December and January. From November to February, adult shoal CPUE was about as high or higher than that for channels (Figure 50). From March to May, shoals were used almost exclusively. From June through October there was a shift from higher shoal use to higher channel use.

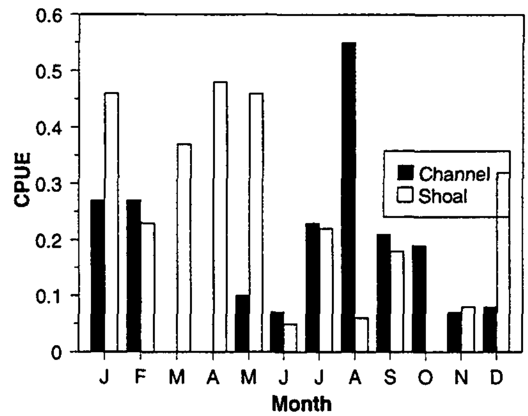

Figure 50 Depth distribution of adult diamond turbot collected with otter trawl (shoal and channel). Data are mean CPUE by month for 1981 to 1988.

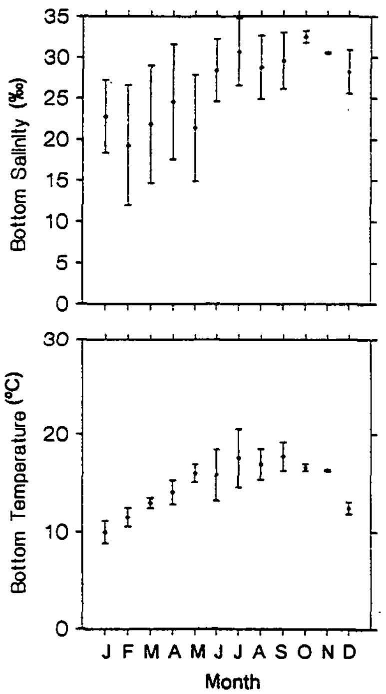

Figure 51 Salinity (‰) and temperature (°C) distributions of adult diamond turbot collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month from 1981 to 1988.

In the beach seine, juvenile diamond turbot were captured at salinities ranging from 4.9‰ to 33.3‰ ($\bar{\chi}$ = 24.5 ± 7.6‰) and at temperatures from 12.0 to 24.8 °C ($\bar{\chi}$ = 17.8 ± 4.4 °C). Only 4 of the 19 juveniles caught by the beach seine came from salinity <22.2‰. Adult diamond turbot were captured primarily from polyhaline and euhaline regions, though 1 was captured at a salinity of 8.4‰ (Figure 51). The lower end of their salinity distributions ranged from 8.4‰ to 14.8‰ during January to May, when their shoal orientation increased their vulnerability to rapidly declining salinity associated with high outflow events (see Figure 51). From June through December, adults were collected from salinity ≥22‰. This increase in their salinity distribution was also reflected in a move into channels by some fish (see Figure 50).

Adult diamond turbot faced temperatures from 8 to 21.3 °C. As estuarine temperatures increased from January to May, adults were found in increasingly warm temperatures: means ranged from 8.0 °C in January to 16.0 °C in May (see Figure 51). From May to November, mean temperatures increased only slightly, ranging from 16 to 17.7 °C before declining in December. Although a few adults were collected at temperatures from 19 to 21.3 °C from June to September, only 5 of 24 fish collected within this period during 1981 to 1988 were from temperatures ≥19 °C.

Discussion

Diamond turbot used the estuary during all life stages, including spawning (Eldridge 1975, this study), but the species was relatively uncommon nonetheless. Based upon larval abundance and a 5 to 6 week larval period (Gadomski and Peterson 1988), spawning in the estuary took place from March through October, primarily from July to October, when water temperature was highest. A similar June to October spawning period was observed in Richardson Bay (Eldridge 1977), but Wang (1986) collected larvae in the estuary all year and found a winter peak. In southern California waters, winter-spring (Lane 1975, Kramer 1990a, Kramer 1991b) or spring and fall (Walker and others 1987) spawning peaks were observed. Emmett and others (1991) suggest a spawning temperature preference for 14 to 16 °C was responsible for the winter-spring spawning in southern California and the summer-fall spawning near San Francisco. Although no studies link diamond turbot spawning or egg and larval survival to water temperature, the California halibut, a species with similar spawning and early life history characteristics, needs temperatures >14 °C to insure larval survival (Gadomski and Caddell 1991). Furthermore, the seasonal pattern of larval abundance is very similar for the 2 species in southern California waters (Walker Jr. and others 1987). In this estuary, adult halibut abundance increased in a pattern very similar to that of adult diamond turbot, strongly suggesting that the same factors may be influencing the abundance of each species.

The estuary is close to Cape Mendocino, the northern edge of the diamond turbot's range (Miller and Lea 1972), so juvenile and adult turbot habitats are probably limited by low temperatures. In this estuary and elsewhere, juvenile diamond turbot settled and reared in shallow inshore water (Lane 1975, Kramer 1990a, Kramer 1991b). This shallow water rearing during fall and winter made them vulnerable to rapid drops in salinity from outflow events. Only 2 age–0 fish were collected from <12‰, indicating that high outflow could affect juvenile survival. Juveniles would have been most at risk from San Pablo Bay upstream where none were collected. Increased adult abundance during the 1987–1994 drought suggests that increased salinity during winter and spring either improved juvenile recruitment or increased adult habitat in the estuary. Increased use of San Pablo and South bays, and occasional use of Suisun Bay from 1987 to 1992 showed that adult habitat increased during the drought.

The diamond turbot may be more abundant in the estuary than indicated by present indices because several aspects of its early life history limit its vulnerability to the sampling gear when compared to other flatfish species. First, the diamond turbot spawns within the estuary (Eldridge 1975), reducing the distance between hatching and nursery areas, the distance over which larvae can be captured. Second, its larvae are <2 mm at hatching (Eldridge 1975), smaller than can be efficiently retained by 500 micron mesh. Third, they settle at a small size (4.4 to 8.8 mm SL, Ahlstrom and others 1984), indicating a short pelagic period, 5 to 6 weeks by 1 estimate (Gadomski and Peterson 1988). These traits reduce the number of monthly sampling opportunities that overlap their pelagic period. Finally, late-stage larvae and small juveniles seek backbays and very shallow water (about 1 m) for early rearing (Kramer 1990a, Kramer 1991b). Beach seine sampling was only conducted on open beaches, not in the backbays or sloughs that may be principal habitat. This mismatch between sampling areas and turbot habitat may have extended to otter trawl sampling too. The lack of fish in the 120 to 180 mm range suggests that these fish may have selected depths less than the 2 to 2.5 m minimum depths sampled with the otter trawl.

California Tonguefish

Introduction

The family Soleidae has only one representative in the Pacific Ocean, the California tonguefish, *Symphurus atricauda,* (Robins and others 1991). Due to its small size (maximum length = 210 mm, Miller and Lea 1972), the tonguefish has no commercial or recreational fishery value, but is eaten by the California halibut (Ford 1965). It ranges from Baja California northward to Big Lagoon, Humboldt County, California (Miller and Lea 1972). After the 1982–1983 El Niño, tonguefish were caught as far north as Greys Harbor and Samish Bay, Washington (Dinnel and Rogers 1986).

Egg development studies show that in southern California waters, the tonguefish spawns from May through October (Goldberg 1981). The larvae are pelagic and transform between 19 and 24.2 mm SL (Ahlstrom and others 1984). They settle in deeper coastal waters (≥9 m), then move to shallow (<7 m) open coastal waters and bays (Kramer 1990a, Kramer 1991b). The 51 to 100 mm length class is collected from bays but not the open coast, whereas, larger size classes are collected from both areas (Kramer 1990a, Kramer 1991b). It is found from 1.5 to 84 m (Miller and Lea 1972). Maturing females average 136 mm SL and range from 114 to 155 mm SL (Goldberg 1981). The lower end of this range approximates the size at first maturity for females. No information exists for male size at maturity.

The California tonguefish is a nocturnal feeder, remaining buried in the bottom during the day (Allen 1982). This diel behavior reduces its vulnerability to daytime trawling (DeMartini and Allen 1984).

Methods

The otter trawl length frequency data (mm TL) were used to separate fish into juvenile and age–1+ classes. A 1 January hatch date was assumed for all juveniles, even though data suggests fish were hatched in the previouse calendar year. Monthly cutoff lengths for separation of age–0 from age–1+ fish were: 65, 70, 80, 90, 95, 100, 110, 115, 120, 125, 130, and 135 mm for January to December, respectively. Tonguefish were considered recently settled until ≥40 mm TL. Abundance indices for each age class were based upon February to October monthly indices. Seasonal abundance indices were based upon mean CPUE by month for 1981 to 1988. For seasonal distribution descriptions, monthly CPUE was averaged for 1981 to 1988. These same years were used for salinity, temperature, and channel-shoal analyses. Conversion of standard length (SL) to total length (TL) was accomplished by using the following equation: $SL = 0.917 \times TL$ (mm) (Kramer 1990a).

Results

Length Analyses

The plankton net caught 5 juvenile California tonguefish but no larvae (see Table 1). The 4 juveniles caught in February 1983 measured 25, 26, 26, and 41 mm TL, and 1 caught in May 1983 measured 44 mm. The smallest tonguefish in the otter trawl, 34 mm, was collected in February 1992. The only other recently settled fish (36 mm) captured by the otter trawl was taken in February 1994.
Based on length, 2 age classes were common in the estuary (Figure 52). Most juveniles entered the estuary when ≥40 mm. Between March and October, juveniles grew about 7 mm per month (see Figure 52). Because of the timing of juvenile entry and age–1+ emigration both age classes were present coincidentally only from June to August. A 3rd age class, represented by fish >150 mm, was present from March to May, but very few were collected. The largest tonguefish, 186 mm, was taken in March 1983.

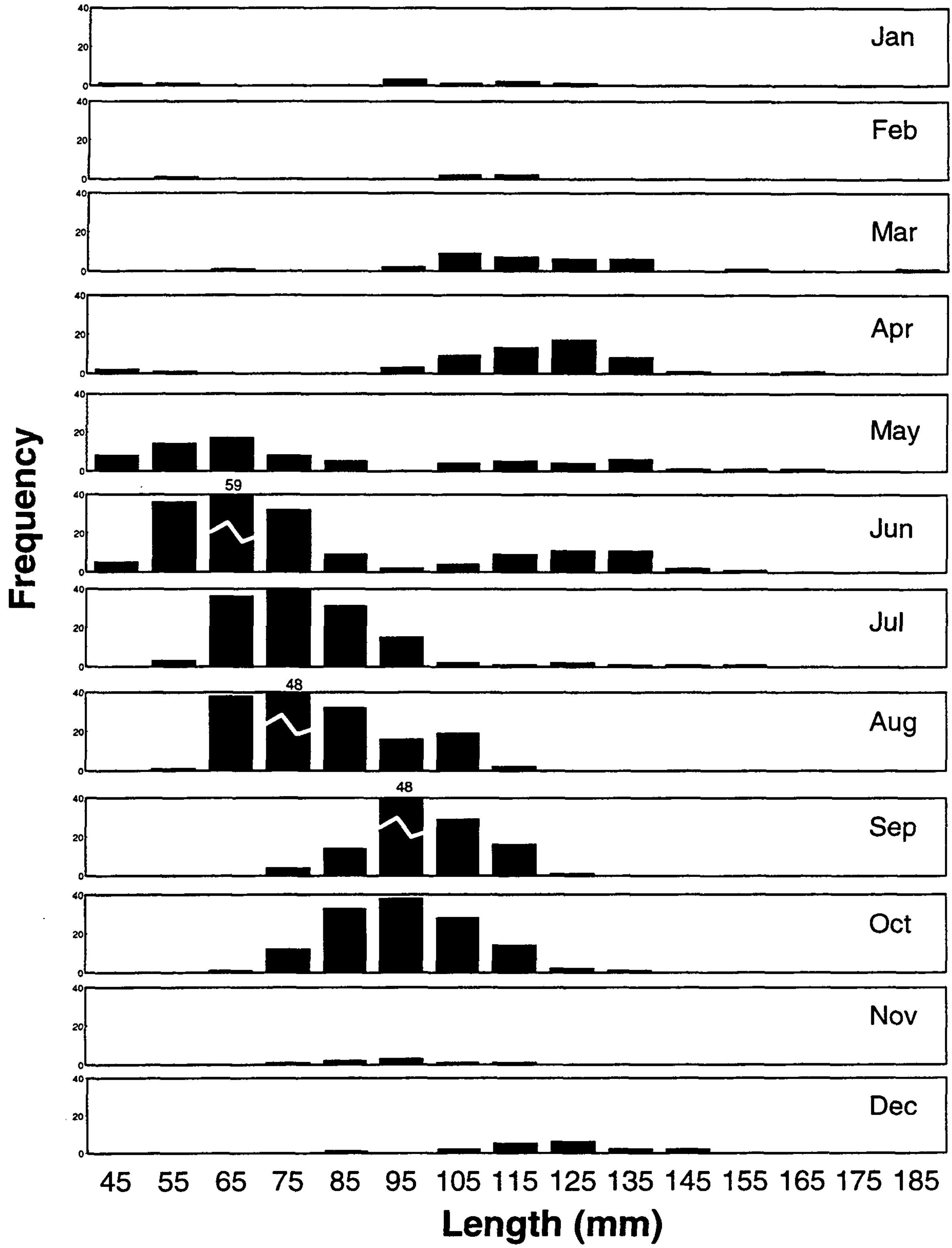

Figure 52 Length frequency (mm TL) by month of California tonguefish collected with the otter trawl from 1981 to 1988. Fish <40 mm were considered recently settled.

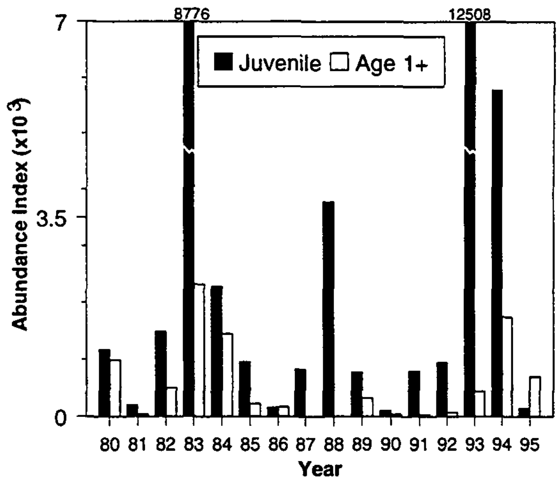

Figure 53 Annual abundance of juvenile and age–1+ California tonguefish collected with the otter trawl from 1980 to 1995. Data are mean February to October abundance indices for both age classes.

Table 21 Monthly abundance of juvenile California tonguefish captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		156	135	0	0	1001	1797	4062	1677	1704	505	0	1170
1981	0	0	0	0	0	0	216	1298	134	243	0	0	210
1982	532	0	0	0	6006	1823	2720	717	3400	4790	216	216	1494
1983	0	0	0	668	1786	20213	13317	26657	1617	16510	1406	2006	8776
1984	0	0	0	0	2757	6858	4866	1417	5605	1758	0	162	2278
1985	0	281	281	0	0	1650	1355	892	2921	1244	0	0	958
1986	0	0	0	0	0	243	688	406	162	0	0	189	167
1987	0	0	0	0	0	0	467	1584	5047	378	435	352	831
1988	0	0	0	219	2432	9492	8496	9288	5638	865	0	557	3778
1989	0	0	0	529	779	748	1001	3187					781
1990		0	0	0	0	219	281	281	0	189			108
1991		0	0	0	438	1392	1695	2807	1007	313			802
1992		375	0	0	2038	4770	2134	0	1248	0			947
1993		0	344	6381	10970	25004	40392	32880	1850	5717			12508
1994		250	297	532	2126	14449	9162	16303	9280	1800			5786
1995	0	0	0	0	831	641	500		0	0	0	0	143
1981–1988	67	35	35	111	0	5035	4016	5282	3066	3224	257	435	

Abundance and Distribution of Juvenile and Age–1+ Fish

Annual Abundance

Juvenile California tonguefish abundance peaked 3 times during the study period: high peaks in 1983 and 1993 to 1994, and a smaller peak in 1988 (Figure 53, Table 21). Minima occurred in 1981, 1986, 1990 and 1995 (see Figure 53). Age–1+ abundance indices followed a pattern much like that of juveniles, but at much reduced levels. They peaked in either the same year as juveniles did (for example, 1983) or in the next year (for example, 1988 and 1993) (see Figure 53, Table 22). No age–1+ fish were caught in 1987 and very few in 1988.

Table 22 Monthly abundance of age–1+ California tonguefish captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		2091	3813	1433	258	1298	0	0	0	0	0	0	988
1981	568	0	0	189	0	0	0	0	0	216	0	0	45
1982	0	0	0	402	3461	379	0	0	0	278	0	0	502
1983	278	402	4361	10808	0	4456	838	0	0	0	0	0	2318
1984	216	0	4793	243	2082	5517	189	0	0	216	0	0	1449
1985	568	216	189	0	0	1298	352	0	0	0	0	0	228
1986	0	162	0	784	0	433	162	0	0	0	0	0	171
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	115	0	0	651	13
1989	594	625	0	541	189	243	0	657					322
1990		0	379	0	0	0	0	0	0	0			42
1991		0	297	0	0	0	0	0	0	0			33
1992		0	0	0	0	0	0	0	657	0			73
1993		0	0	0	0	0	0	1936	0	2049			443
1994		3972	6986	594	1157	1444	514	344	281	352			1738
1995	649	3229	1777	560	0	0	0		0	0	0	0	696
1981–1988	204	98	1168	1553	693	1510	193	0	14	89	0	81	

Seasonal Abundance

Juvenile California tonguefish entered the estuary post-settlement starting in January, but their abundance was low until June when it increased sharply (Figure 54, see Table 21). Juvenile abundance was high from June to August, then declined through November and remained low in December (see Figure 54). In high abundance years (that is, 1983, 1988, 1993, and 1994), juveniles were consistently collected in April or earlier, whereas in low abundance years (that is, 1981, 1986, 1990, and 1995) they were not collected until May or later (see Table 21). Age–1+ California tonguefish either remained in or returned to the estuary in low numbers in January and February (see Figure 54, see Table 22). Age–1+ abundance increased in March and April, declined in May, increased in June, then declined to zero in August. From September through December, they were rare in the estuary.

Annual Distribution

Juvenile California tonguefish were generally collected from South Bay to San Pablo Bay, but in 1991 their distribution extended into Suisun Bay (Figure 55). Peak CPUE occurred in either South Bay or Central Bay. CPUE was high in San Pablo Bay during 1988 and 1994, both low outflow years. In most low abundance years (for example, 1986, 1990, and 1995), juveniles were not collected in San Pablo Bay and in 1981 they were not collected in South Bay (see Figure 55). Although age–1+ fish were collected in Suisun Bay and San Pablo Bay, they were extremely rare there (Figure 56). Before 1992, adults were abundant in South Bay only in 1983. After 1992, adults became more common in South Bay and were quite abundant in 1994.

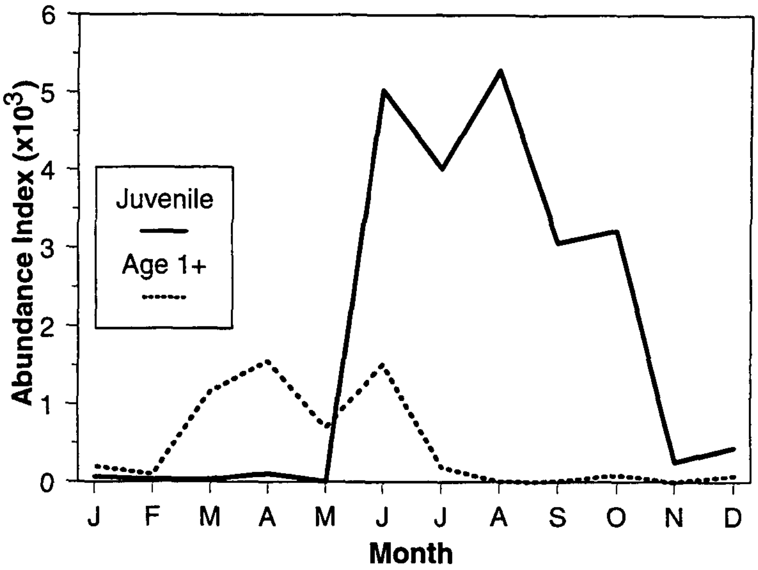

Figure 54 Seasonal abundance of juvenile and age–1+ California tonguefish collected with the otter trawl. Data are mean monthly abundance indices for 1981 to 1988.

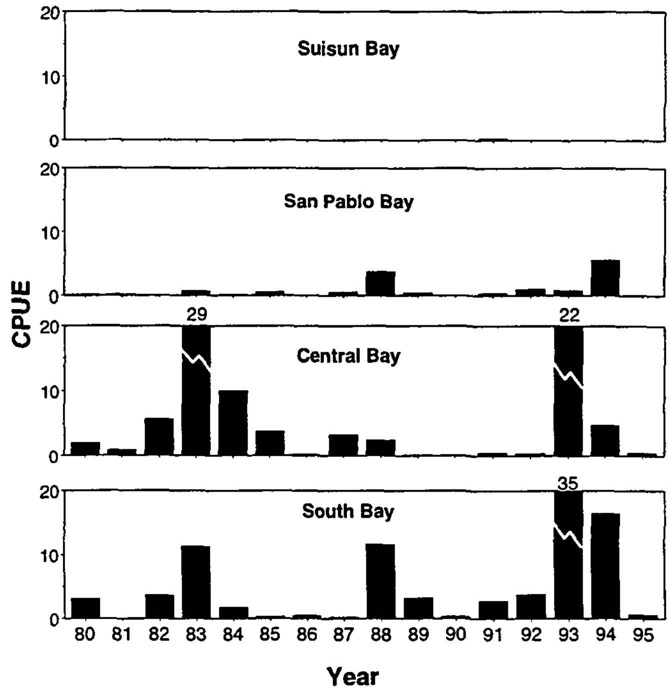

Figure 55 Annual distribution of juvenile California tonguefish collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region.

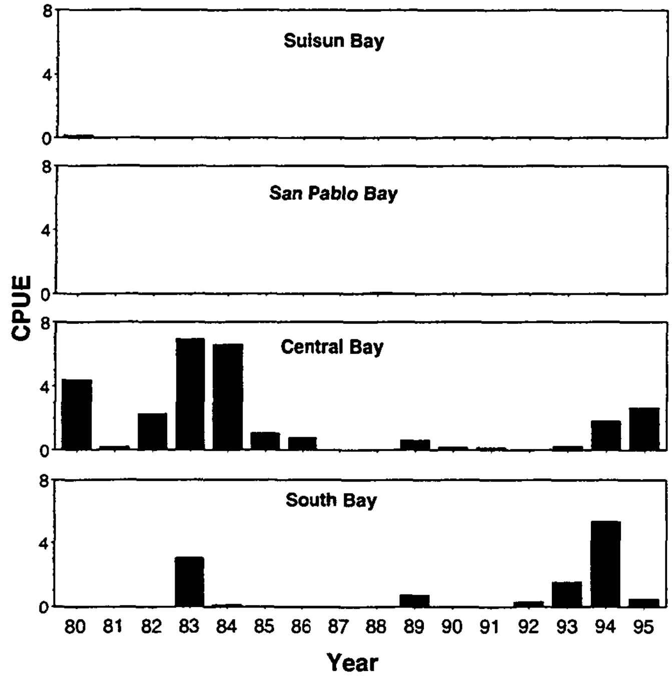

Figure 56 Annual distribution of age–1+ California tonguefish collected with the otter trawl from 1980 to 1995. Data are mean February to October CPUE by region.

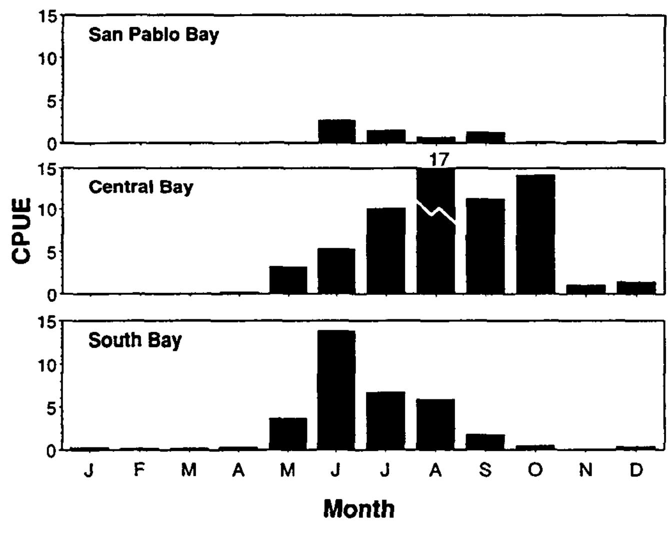

Figure 57 Seasonal distribution of juvenile California tonguefish collected with the otter trawl. Data are mean CPUE by month and region for 1981 to 1988.

Seasonal Distribution

From January through March, juvenile California tonguefish were captured only in South Bay (Figure 57). Beginning in April, CPUE increased in South and Central bays and by May fish entered San Pablo Bay. Juvenile CPUE in South and San Pablo bays increased to a peak in June, then declined to low levels the rest of the year. In Central Bay, juvenile CPUE continued to increase until August and remained high from August through October before declining rapidly in November and remaining low in December.

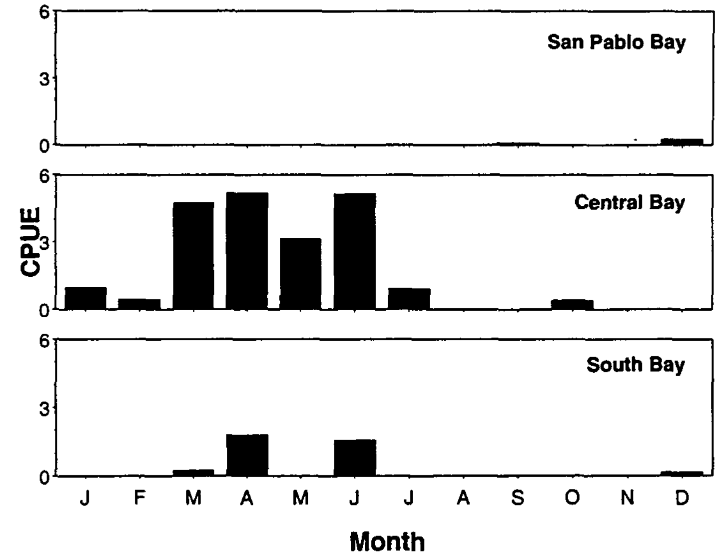

Figure 58 Seasonal distribution of age–1+ California tonguefish collected with the otter trawl. Data are mean CPUE by month and region for 1981 to 1988.

In January and February, age 1+ California tonguefish were present only in Central Bay (Figure 58). In March, CPUE increased in Central Bay and to a lesser degree in South Bay. CPUE remained relatively high in Central Bay and low in South Bay from March to June and then declined in both regions. After July, age–1+ tonguefish were rare in the estuary.

From January to March, the few juvenile California tonguefish collected were in channels (Figure 59). Beginning in April and continuing to July, juveniles inhabited both channels and shoals but favored the channels. Higher shoal use in August was an anomaly resulting from a single high catch at a relatively deep (9 m) shoal station (#211) in August 1983. When most juveniles emigrated from San Pablo and South bays in September and October, the use of channels increased sharply (see Figure 59). In November and December, the few remaining juveniles were more evenly distributed, but still favored channels.

The depth distribution of age–1+ California tonguefish in January and February was similar to that of juveniles during the previous November and December (see Figure 59). From March to June, when abundance was high most age–1+ fish were collected in channels. From July through November the few remaining age–1+ fish were caught at channel locations. In December, a few age–1+ fish were again collected from both channel and shoal locations.

Juvenile California tonguefish were collected at salinities from 12.6‰ to 34.3‰. During their estuarine immigration period (April to June), juvenile tonguefish were collected over a broad salinity range of 12.6‰ to 31.6‰ and monthly means of 24.3‰, 22.4‰, and 23.9‰ (Figure 60). From June to October, juveniles inhabited progressively more saline water as estuarine salinity increased as outflow decreased seasonally (see Figure 60), and also as juveniles moved to Central Bay (see Figure 57). In October, juveniles inhabited salinities ranging from 27.4‰ to 34.2‰ and a mean of 31.8‰. By December, juveniles were again collected from salinity as low as 19.8‰ and a mean of 24.1‰.

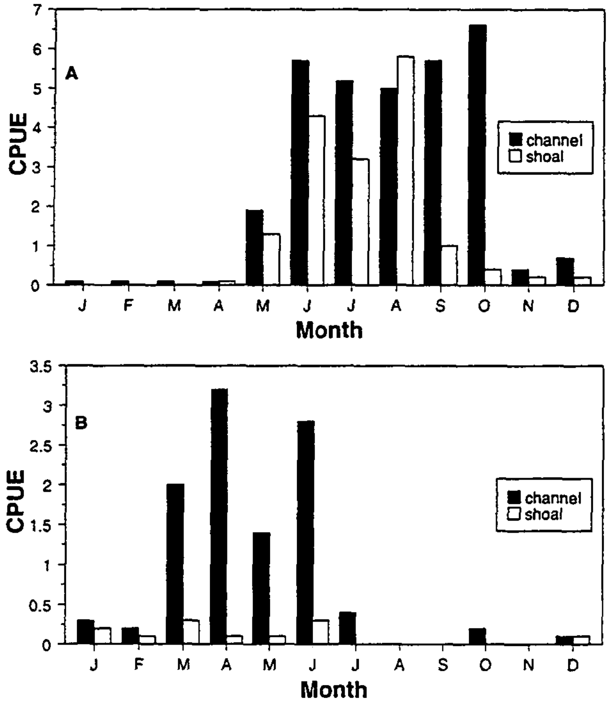

Figure 59 Depth distribution (shoal and channel) of (A) juvenile and (B) age–1+ California tonguefish collected with the otter trawl. Data are mean CPUE by month for 1981 to 1988.

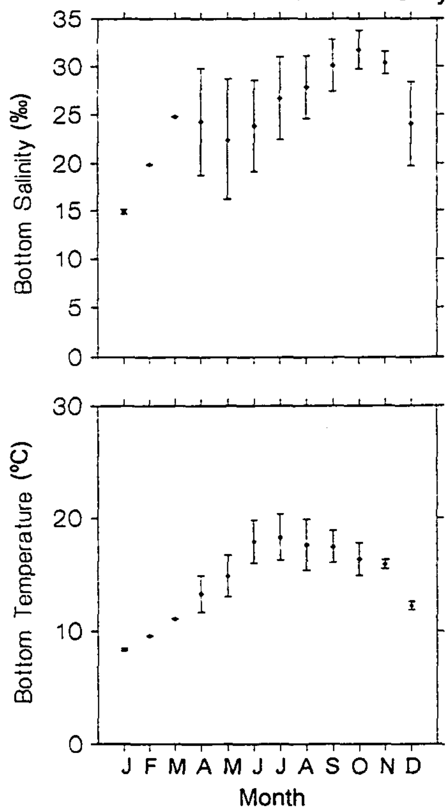

Figure 60 Salinity (‰) and temperature (ºC) distributions of juvenile California tonguefish collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month for 1981 to 1988.

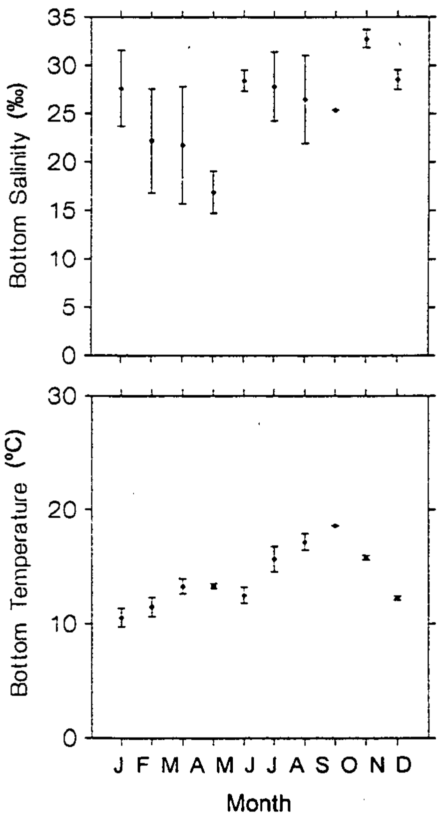

Figure 61 Salinity (‰) and temperature (°C) distributions of age–1+ California tonguefish collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity and temperature by month for 1981 to 1988.

The mean monthly temperature juveniles were found in ranged from 8.4 °C in January to 18.3 °C in July (see Figure 60). Temperature increased steeply from January to June but was fairly stable from June to October, and declined sharply in December. Their overall temperature range was from 8.3 to 22.4 °C.

Age–1+ California tonguefish were collected at lower salinity and from a narrower temperature range than juveniles: 5.4‰ to 33.7‰ and 9.6 to 18.6 °C. The age–1+ salinity distribution was initially high in January ($\bar{\chi}$ = 27.6‰) and declined to April ($\bar{\chi}$ = 16.9‰), reflecting the delay between outflow and the salinity response in Central Bay. In particular, their salinity distribution was strongly influenced by high outflow in 1983 when bottom salinity was depressed throughout the estuary from February to May (see Salinity and Temperature chapter, Figures 1 through 5). From May to July, mean salinities ranged from 26.5‰ to 28.4‰ (Figure 61). From January through March, the age–1+ fish were found in increasingly warm water: means ranged from 10.5 to 13.3 °C (see Figure 61). In April and May, mean temperature remained stable between 12.5 to 13.5 °C, before increasing from June to peak in September of 18.6 °C. During the later period very few age–1+ fish remained in the estuary (see Figure 58).

Discussion

California tonguefish used the estuary as a nursery and feeding area, entering as 40 to 80 mm juveniles, and dispersing onto shoals during summer, then moving to channels in fall and, for some, temporarily out of the estuary during winter. Cooling water temperatures may have stimulated a migration to warmer coastal waters in November and December. Low winter abundance may also have resulted from low activity (low catchability) in the cool water. Presumably fish remain buried in the substrate when not foraging, and most foraging occurs at night (Allen 1982).

Most California tonguefish left the estuary after their 1st summer or before completing their 2nd summer of residence. Emigration during their 2nd summer may be a spawning migration based upon the size of age–1 fish May to July (this study), female size at maturity (Goldberg 1981), and their May to October spawning period (Goldberg 1981, Kramer 1990a, Kramer 1991b). A few post-spawning fish returned during the next winter and spring as age–2 fish, but the estuary did not appear to be their principal habitat.

Elsewhere, the California tonguefish uses inshore waters similarly to that of the San Francisco Estuary. In southern California, tonguefish settle on the open coast at depths ≥9 m from fall through early spring, move to shallow (3.5 to 5 m) bay waters at 51 to 100 mm SL (56 to 109 mm TL) in summer, and then move to deeper water as they grow beyond 100 mm SL (Kramer 1990a, Kramer 1991b). Although they inhabit bays during other seasons, fish >101 mm SL are most common on the open coast during summer (Kramer 1990a, Kramer 1991b). Since this author separated fish into 50-mm size groups, it was not possible to determine a more precise length at emigration. In the estuary, juvenile tonguefish appeared to emigrate at 110 to 120 mm, or by November, based upon the reduced catch.

The abundance of juvenile tonguefish in the estuary appeared to be partly a function of fall and winter water temperature. The center of the California tonguefish distribution is considered to be the San Diegan Faunal Region (Allen 1982 in Kramer 1990a); thus, tonguefish in the estuary are near the historic northern limit of their range (Roedel 1953). Moreover, tonguefish spawning and early larval periods coincide with peak water temperatures in southern California (Walker and others 1987), suggesting a link between water temperature and the abundance of tonguefish at the northern end of their range. Increased abundance occurred during 1983, 1988, 1993, and 1994; each increase occurred after a year with higher than average fall sea-surface temperatures (see Salinity and Temperature chapter, Figure 11).

A 2nd factor apparently influencing California tonguefish abundance was northward transport of eggs and larvae. In October, at the end of the tonguefish spawning period, the northward Davidson current begins to flow and by January the current reached speeds of 0.2 knot (288 km per month) (Reid and Schwartzlose 1962, Wyatt and others 1972). Based upon a size at settlement similar to or larger than that of the English sole, tonguefish larvae should remain pelagic for more than 2 months, allowing about 575 km of northward transport for fall-spawned larvae before settlement. During extreme conditions considerably longer transport distances can occur. Anomalous warm ocean temperatures and strong downwelling during fall 1982 and winter 1983 (Norton and others 1985) were responsible for the >400 km range extension of tonguefish in 1983 (Dinnel and Rogers 1986). These same processes resulted in increased abundance in the San Francisco Estuary. The 2 El Niño events in 1982–1983 and 1992–1993, produced strong, positive, fall to winter temperature anomalies, strong to moderate Davidson currents (Norton and others 1985), and the 2 largest tonguefish year classes recorded (see Figure 53). Other, more moderate, temperature anomalies (not El Niño conditions) also resulted in increased abundance: 1979–1980, 1983–1984, 1987–1988 and 1993–1994 (compare Salinity and Temperature chapter Figure 11 with Figure 53). Thus, increased local ocean temperatures lead to increased abundance, possibly through local spawning and recruitment, but the largest year classes resulted from increased temperatures and strong northward transport of eggs and larvae.

Once in the estuary, California tonguefish inhabited intermediate to deep waters (primarily channel stations) in the mostly euhaline conditions of Central Bay and northern South Bay. Although juveniles and adults were captured in mesohaline waters there was no indication that they sought these conditions. On the contrary, capture at low salinity occurred in Central and South bays (normally euhaline) only during extremely high outflow conditions. Their persistent capture in low salinity water suggests some tolerance for it and no mechanism to avoid it.

Uncommonly Collected Flatfish Species

Pacific sanddab, *Citharichthys sordidus,* range from Cape San Lucas, Baja California northward to the Bering Sea, and reach a maximum size of 406 mm (Miller and Lea 1972). Due to their relatively small size, Pacific sanddabs are not as important commercially as other flatfish, nonetheless, they are highly prized by commercial and recreational fishers for their excellent taste (Leos 1992b). In the estuary, 26 Pacific sanddabs were collected between 1980 and 1995, all in the otter trawl (see Table 1). These fish ranged from 36 to 284 mm and all were larger than 159 mm (except for 1 at 36 mm). Almost all were collected from Central Bay (25 of 26) and from January through April (23 of 26). Thus, older juvenile and young adult Pacific sanddabs inhabit the polyhaline and euhaline portions of the estuary during the cooler months, but the estuary is not prime habitat for them.

Sand sole, *Psettichthys melanostictus,* range from Port Hueneme to the northern Gulf of Alaska, and reach a maximum length of 533 mm (Miller and Lea 1972). In the estuary, sand sole from 2.7 (yolk sac larvae) to 453 mm were collected. All the larvae ($n = 20$) were collected from February through May and recently settled fish (15 to 30 mm, $n = 7$) were taken from April to August, with an additional fish caught in October. Seventy-nine juvenile and adult sand sole were collected during the study period, primarily in the otter trawl (see Table 1). Annual catch (February to October) varied from 0 in 1988 to 10 in 1993. Catch in all other years varied between 1 and 6. About 64% of the sand sole collected in the otter trawl ($n = 70$) came from Central Bay, 12% from South Bay, 17% from San Pablo Bay, and 7% from Suisun Bay. The small number of larvae collected indicates that sand sole spawning takes place on the open coast. Near Yaquina Bay, Oregon, nearshore, coastal spawning was indicated based upon larval densities (Pearcy and Myers 1974, Richardson and Pearcy 1977). Sand sole of all ages use the estuary as an extension of their coastal habitat.

Curlfin sole, *Pleuronichthys decurrens,* range from San Quintin Bay, Baja California, northward to northwest Alaska, and reach a maximum size of 368 mm (Miller and Lea 1972). One hundred and twenty-one curlfin sole ranging in length from 36 to 188 mm were collected in the estuary with the otter trawl (see Table 1). About 81% of the catch came from the deepwater station #213, and an additional 16% from Central Bay channel stations #110, #214 and #215. There was no seasonal pattern to their capture, but there was an annual pattern. Before 1992, annual catch (February to October) varied from 0 in 1981 to 4 in 1985; subsequently, annual catch was 14, 34, 20, and 7 for 1992 to 1995, respectively. Juvenile curlfin sole habitat appears to be in the deepest stations in Central Bay.

Only single individuals of several other species have been captured (see Table 1). A 109 mm C-O sole, *Pleuronichthys coenosus,* was caught at station #105 in January 1987. A single larval hornyhead turbot, *Pleuronichthys verticalis,* was caught at station 211 in July 1987. A single hybrid sole, *Inopsetta ischyra,* at 120 mm was taken at station #214 in October 1990. This form is considered a hybrid cross between the English sole and the starry flounder rather than a true species (Miller and Lea 1972). The specimen was right-eyed, had the body shape (that is, a pointed head and 1 eye visible from the blind side) and olive tan coloration of an English sole, but distinct, alternating light tan and dark gray bands similar to a starry flounder. Fin ray counts were dorsal 68, anal 54, caudal 18, pelvic 6, and pectoral on the blind side 11. The dorsal ray count is intermediate to counts for the English sole and the starry flounder (Miller and Lea 1972).

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Notes

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